THE HISTORICAL EXPLOITATION OF CHONDRICHTHYANS IN FALSE BAY, SOUTH AFRICA AND ASSESSMENT OF THEIR CONSERVATION STATUS

by

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ABSTRACT

Commercial fishing in False Bay, South Africa, began in the 1600s. Today chondrichthyans are regularly taken in multiple fisheries throughout the Bay. Using time series data and life history information I assessed the vulnerability of chondrichthyans to exploitation in False Bay. Extensive time series from five fishing methods, between 1897 and 2011, enabled catch trend analyses for chondrichthyans as a whole as well as for specific species. Commercial linefish, beach seine, and recreational angling provided the best source of data because they cover the range of habitats found in the Bay and are the least selective methods. According to previous records, six species' (*Etmopterus granulosus, Raja straeleni, Carcharhinus brevipinna, Torpedo fuscomaculata, Dasyatis thetidis,* and *Gymnura natalensis*) presence in False Bay were extralimital, indicating a possible range extension. The five most commonly caught species across all methods were *Galeorhinus galeus*, *Mustelus mustelus*, *Rhinobatos annulatus*, *Callorhinchus capensis*, and *Notorynchus cepedianus*. Of the 38 species found to occur in False Bay, 28 showed no significant trends for any fishing methods, this was partly the result of a lack of species-specific identification. Of the ten species with catch trends, four showed a common trend across methods, two increasing (*M. mustelus* and *Carcharhinus brachyurus*) and two decreasing (*G. galeus* and *Triakis megalopterus*). One genus (*Raja* spp.) also showed a common trend of decreasing catch. An index of productivity, or resilience against exploitation, was used in conjunction with information on life history, and level of population decline, to assess chondrichthyan species in False Bay. The assessment identified populations that were *stable* (*M. mustelus* and *C. brachyurus*), *vulnerable* (*C. capensis* and *Raja* spp.), or *threatened* (*G. galeus* and *T. megalopterus*) by exploitation, as well as those species of *conservation concern* (13 species) or with *unknown* status (20 species and one genus). The False Bay status assessment was used to determine which species are most in need of monitoring, conservation management or protection.

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CHAPTER 1.

LITERATURE REVIEW

1.1. Global crisis

The current rate of biodiversity loss is several orders of magnitude higher than the background historical extinction rate (Mace et al. 2005). Human exploitation has spread across land and sea, modifying ecosystems and eliminating species, particularly large vertebrates (Diamond et al. 1989; Alroy 2001; Jackson et al. 2001). Marine biodiversity is under increasing threat worldwide, primarily as a result of over-harvesting, pollution and climate change (Field et al. 2009). However, it is only in the last half-century, as fishing fleets expanded rapidly in the open ocean (Pauly et al. 2002), that large marine predators have been subject to intense exploitation (Myers & Worm 2003; Roberts 2007). The impact of fisheries on cartilaginous fishes should be of particular concern. Cartilaginous fishes are of the taxonomic order Chondrichthyes and include sharks, rays, skates and chimaeras. A recent assessment, led by the International Union for Conservation of Nature (IUCN), estimated 20% of the 547 shark and ray species on its Red List to be threatened with extinction (IUCN 2006).

The total world catch from all wild marine stocks has steadily increased from 1950 (FAO 2005), and as a result, the majority (76-84%) of the world's fish stocks are fully exploited, overexploited or depleted (Hilborn et al. 2003; FAO 2010). Correspondingly, the trend in world Chondrichthyes catch is upwards, despite increasing recognition of the need to manage these stocks and rebuild depleted populations (Lack & Sant 2006). The harvest of cartilaginous species has been identified as the greatest current threat to their diversity and abundance, with risk from commercial and industrial fisheries far out-weighing that of artisanal and subsistence harvests (Stevens et al. 2005; Worm et al. 2005).

The shark fishery, in particular, feeds a global and growing market for shark meat, fins, cartilage, skin (leather), oil, teeth, gill rakers and jaws (Rose 1996). Dried shark fins are especially in high demand as the main ingredient in Asian soups (Rose 1996). Blue sharks (*Prionace glauca*), a major bycatch species of tuna longlines in the Pacific, were of low economic value prior to 1980 and were generally released alive, <5% of hooked sharks were finned. However, the expansion of Asian markets for shark fin resulted in increased mortality, presently >60% of sharks are finned (Schindler et al. 2002). Recent research also indicates large potential errors in FAO reporting based on market estimates of shark fins, from which the global fin trade is estimated to be up to three or four times higher (Clarke et al. 2006).

The figures above highlight the potential threats from illegal, unreported and unmanaged (IUU) fishing. IUU-fishing refers to harvesting that does not comply with national, regional or global fisheries conservation and management obligation (FAO 2001), and for sharks, illegal harvest primarily targets species for the lucrative fin trade (Clarke et al. 2006). The lack of specific management and reporting mechanisms for IUU fishing has resulted in unchecked exploitation, and many chondrichthyans might be susceptible to extinction from stochastic processes entirely unrelated to fishing pressure itself (Field et al. 2009).

1.2. Why chondrichthyans?

Chondrichthyans first appeared 400 million years ago (Compagno 1990), and have survived two major mass extinction periods (Cailliet et al. 2005). Presently thought to approach 1 200 species, they range widely across diverse habitat from the coastal margins and continental shelf (~50% of species) to the upper pelagic waters (~5%) and oceanic depths (~35%) around the world; the remaining live in freshwater (~5%) or occur within several of these habitats (~5%) (Musick 2005; Compagno 1990). Within these habitats, some have wide distributions, while others are endemics restricted to specific habitats (Field et al. 2009). Although some chondrichthyans (35 species) occur only in freshwater, the focus will remain on those marine species that live either partially or totally in the marine environment. Due to the wide range of habitats in which chondrichthyans occur they are primarily threatened by a gamut of fishing methods and to a lesser degree by habitat loss and degradation, whereas the effects of invasive species and pollution are too poorly understood to predict long-term impacts (Field et al. 2009).

Chondrichthyans have been the focus of many marine ecological studies for two reasons. Firstly, chondrichthyans exhibit life history traits that bestow on most a low intrinsic rate of population increase (Musick et al. 2000b). These unproductive life-history characteristics and low population growth rates render them less able to withstand fishing mortality than the earlier-maturing, shorter-lived and more fecund bony (teleost) fishes with which they are frequently captured (Musick 1999a; Stevens et al. 2000). As a result, recovery is expected to be slow (Musick et al. 2000b) and so, cartilaginous species are likely to be impacted more than others in the community. Secondly, chondrichthyans are positioned high in the food chain as predators, many as top order predators, and thus have comparatively low abundances (Bonfil 1994). In addition, predators, influence prey communities through direct predation and by inducing costly anti-predator behaviour (Creel & Christianson 2008). As a result, chondrichthyans have a fundamental impact on the structure and function of marine ecosystems (Heithaus et al. 2008).

From an ecosystem perspective, perhaps more important than the actual magnitude of decline of predator populations is the shift in species composition and relative abundance in the communities released from predation (Jackson 2008; Field et al. 2009). As a result of top predator removal, meso-consumers are left to increase in abundance impacting several trophic levels and affecting other fisheries (Myers et al. 2007). This phenomenon is referred to as a trophic cascade (Pace et al. 1999). Despite extensive literature on trophic cascades, the consequences of removing large marine predators remain somewhat uncertain (Bascompte et al. 2005; Frank et al. 2005). One example of a marine trophic cascade, described by Myers et al. (2007), clearly shows release from large shark predators can have major consequences for an ecosystem.

1.3. Direct- and indirect-fishing

Stemming from a history of exploitation in fisheries and despite their known vulnerability to overfishing, chondrichthyans have continued to be caught both indirectly as bycatch and as targets in directed fisheries (Musick et al. 2000b). Harvesting of chondrichthyans continues largely unabated because of the comparatively high productivity of the primary target species and limited interest in managing these species (Lack & Sant 2006).

1.3.1. Targeted Fishing

Commercial fisheries directly targeting shark started as early as the late 18th century, steadily growing from the 1920s (Bonfil, 1994), with landings increasing by 2% annually since 1985 (FAO 2005). Directed shark fisheries often follow a pattern of 'boom-and-bust', brief periods with high harvest followed by severe declines in catch rates, as well as the subsequent fishery's closure and a long, slow period of recovery (Camhi et al. 1998). Examples across the world of this pattern in shark fisheries can be found in Stevens et al. (2000).

1.3.2. Mixed fisheries and bycatch

Although directed fishing can have severe impacts on target species, possibly the greatest potential threat to chondrichthyans worldwide is indirect harvest, where they represent bycatch in mixed-species fisheries (Bonfil 1994). Serious population reductions in many species taken as bycatch have been documented (Stevens et al. 2000). The threat for bycatch is so severe because of the low priority and economic value of secondary species catches (chondrichthyans), and because of limited or no reporting of captured and discarded bycatch species (Field et al. 2009). Almost 50% of the estimated global catch of cartilaginous species is taken as bycatch, does not appear in official fishery statistics, and is almost totally unmanaged (Bonfil 1994). These fisheries can generally remain economically viable, at least temporarily, because the target or primary species tend to be more productive than the secondary species, who often sustain large population declines or are driven to extinction (Musick 1999a). For example, blue shark (*P. glauca*) bycatch is considerable in the central Pacific and roughly comparable to yellowfin tuna (*Thunnus albacares)* catch rates, 4-18 and 2-20 captured per 1000 hooks respectively, most of which are now finned (Schindler et al. 2002). Pelagic longline fisheries worldwide remove up to eight million sharks annually, or one-third of the world catch of all chondrichthyans (Bonfil 1994), however the actual rate is likely to be much higher (Clarke et al. 2006).

1.3.3. Recreational fishing

Although chondrichthyans are mainly bycatch species for many recreational fishers, others also target them as game or sport fishes (Stevens et al. 2005). Recreational fishing catches are typically small relative to commercial catches, although few data are available specifically for chondrichthyans due to a general absence of formal reporting requirements (Field et al. 2009). Nevertheless, catches of large coastal sharks on the east coast of the USA and in the

Gulf of Mexico are thought to be greater than that taken by the commercial fishery, such that the two mortality sources combined are alleged to be the primary drivers of the decline in blacktip (*Carcharhinus limbatus*) and sandbar sharks (*Carcharhinus plumbeus*) (Cortes et al. 2002). As another example, recreational spearfishing of grey nurse sharks (*Carcharias taurus*) during the 1960s and 1970s on the east coast of Australia contributed to such a large decline in population size that it led to their protection in 1984 (Pollard 1996).

1.4. Management and protection

Adequate monitoring of chondrichthyan populations at any level is generally rare and hindered by the relative inaccessibility of the marine ecosystem, lack of funding and simply low conservation priority (Dulvy et al. 2008). Thus, for most chondrichthyan species there is a lack of knowledge of population status and extent of exploitation (Castro et al. 1999). As a result, management and conservation of these species has been hampered.

Several reviews in the mid-1990s found that little or no attention was paid by domestic and international fishery management organisations to chondrichthyans, despite their known vulnerability and the increasing volume of catches and trade in their products (Fowler & Cavanagh 2005). Although concern for their status has since been increasing worldwide, and influential organizations like the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), members of the Food and Agriculture Organization (FAO) and the United Nations General Assembly have called for increased monitoring, research and management of cartilaginous stocks, implementation of improved conservation and management has been patchy at best (Lack & Sant 2006).

There are multiple international fisheries agreements, for example, the United Nations Convention on the Law of the Sea, UN Fish Stocks Agreement and FAO Code of Conduct for Responsible Fisheries (Fowler & Cavanagh 2005), however these agreements do not specifically address chondrichthyans. More recently, legislation under CITES (Wijnstekers 2001) and the Convention on Migratory Species (CMS 2012) work to protect threatened species like the white shark (*Carcharodon carcharias*), basking shark (*Cetorhinus maximus*) and whale shark (*Rhincodon typus*). However, not until the development of the International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks), adopted in 1999, was the general conservation and management of all cartilaginous species addressed (FAO 2009). Unfortunately, implementation of this plan by State and regional fisheries management organizations is voluntary and its adoption has been largely disregarded (Lack & Sant 2011).

1.5. Population decline

The reduction and collapse of chondrichthyan populations has been documented around the world. For example, the once common barndoor skate (*Dipturus laevis*) in the northwest Atlantic is near extinction as a result of fishing pressure from commercial trawling. Last estimated at 500 individuals in the 1970s, *D. laevis*, is now virtually absent from commercial trawl catches and only found in a few refuges protected from fishing (Casey & Myers 1998). Similarly, Rogers and Ellis (2000), when comparing historical and current catch data from trawl surveys around the British Isles, found a decline in abundance of large sharks, skate and rays. In addition, a shift in species composition between historic and contemporary surveys was apparent and these changes in the demersal fish assemblages were attributed to a response to commercial exploitation. Other examples include dramatic declines in abundance of large predatory sharks, by more than 96%, in the Mediterranean Sea over the last two centuries (Ferretti et al. 2008), as well as a significant reduction (declines from 60-99%) in small coastal sharks in the Gulf of Mexico (Shepard & Myers, 2005).

Severe depletion of coastal and shelf fisheries has been widely recognised, but the open ocean was still considered one of the last great wild places on Earth (Baum & Myers 2004; Jackson 2008). However, more recently, studies are beginning to indicate otherwise. Baum et al. (2003) estimated, using data from the U.S. pelagic longline fleets targeting swordfish and tunas in the northwest Atlantic, that all recorded shark species, with the exception of makos (*Isurus* spp.), have declined by more than 50% in the past eight to 15 years. Longline fishing and trawling in the Gulf of Mexico reduced the four most common large pelagic shark species by 45-99% in 40 years (Baum & Myers 2004).

These examples clearly show that overfishing is threatening large coastal and oceanic sharks. The magnitude of decline found suggests that several species may be at risk of large-scale extirpation (Baum et al. 2003; Shepard & Myers 2005). Given that in all oceans, longline and other pelagic fisheries are intense and catch many of the same chondrichthyan species, serious declining trends in northwest Atlantic shark abundances may be reflective of a common global phenomenon (Baum et al. 2003; Baum & Myers 2004). While these results are considered by many to be controversial, it is agreed that the overarching trend indicate there have been general declines in many of the fished chondrichthyan species, the debate is instead centred on the magnitude of the declines (NRC 2006; Field et al. 2009). Despite this concern, some chondrichthyan species are more resilient to fishing, and predictions on their individual vulnerability can be made based on their life history and population parameters (Stevens et al. 2000).

1.6. Assessment limitations

A handful of challenges arise regularly when attempting to determine the population trends of almost any cartilaginous species. Firstly, despite widespread exploitation, chondrichthyan catches have been poorly reported in fisheries records, largely due to their traditionally low value relative to the target catch as well as a lack of regulations for reporting bycatch (Rose 1996; Clarke et al. 2005; Dulvy et al. 2008). Secondly, even when catches are reported they are usually not recorded to the species level and are instead lumped together as one category, i.e., "sharks" or "skates". For example, only 15% of all chondrichthyan catches reported to the FAO have been recorded by species (Lack & Sant 2006). This lack of species-specific data poses a significant challenge to quantifying the impacts of exploitation on these species and may mask changes in community structure, declines and local extinction, particularly of larger, slower growing species (Dulvy et al. 2000). One such example, of the impact of imprecise taxonomic identification has resulted in the further depletion of the critically endangered common skate (*Dipturus batis*) (Iglesias et al. 2010).

Thirdly, when attempting to assess population trends over time, a shifting baseline often complicates the process. To understand the full extent of exploitation of any species requires knowledge of their unexploited state (NRC 2006). For many species, however, a historical perspective is difficult or even impossible because of a lack of historical data. But, without it the baseline of what is 'natural' will continue to shift, and ultimately risks becoming complacent about the rarity of species (Pauly 1995; Baum & Myers 2004).

Finally, the biology of chondrichthyans is among the most poorly known and least understood of all major marine vertebrate groups. Detailed information on life history and reproductive dynamics is available for only a few of the species that are of targeted importance (Cailliet et al. 2005). Because of this knowledge gap, population models and demographic analyses have not been widely applied. Where stock assessment or population models are being used, they are mostly designed for r-selected, highly fecund teleost fishes and therefore are inappropriate for understanding the population dynamics of chondrichthyans (Bonfil 1994; 2005). As a result, attempts to determine species vulnerability to exploitation are severely restricted (Cailliet et al. 2005).

1.7. Chondrichthyans in South Africa

Subequatorial Africa is a diversity hotspot for chondrichthyan fishes (Compagno 1999), with all orders, 47 families and roughly 260 species represented. Specifically, South Africa has the highest recorded number of total- and endemic-chondrichthyan species in this region (Compagno et al. 2005a).

1.7.1. Exploitation

The impact of fisheries on chondrichthyans in African waters is not well documented (Kroese & Sauer 1998; Da Silva & Burgener 2007), and effective regulations governing the catch and sale of cartilaginous species are lacking in most African countries (Marshall & Barnett 1997). Reported landings of chondrichthyans in Africa are low and no country ranks in the top twenty worldwide for catch over the period 1985-2000. South Africa reported only 1 665 tonnes of cartilaginous catches in 2000 (FAO 2002), which is comparable to annual estimates of catch for the mid-1990s (Japp 1999). However, actual South African chondrichthyan catch is believed to be at least double those in reported catch data because; firstly, FAO data underestimates actual mortality because they do not include discards (Lack & Sant 2009), secondly the lack of reporting in artisanal fisheries, and finally the large number of nations fishing in African waters (Kroese & Sauer 1998).

In terms of chondrichthyan production and trade, South Africa and Senegal are the only two counties reporting substantive numbers. South Africa produced between 95 and 454 tonnes of frozen shark meat and between 52 and 66 tonnes of shark fin annually from 1998 to 2000 (FAO 2002). Although South African and Senegal are the only African countries reporting exports, declared imports into Hong Kong between 1996-2000 showed that almost every coastal African country exported shark fins, totalling 717 tonnes in 2000 alone (Clarke & Rose 2005), again highlighting a problem with IUU-fishing.

Apart from the catch records of the Natal Sharks Board in South Africa, there has been very little long-term data monitoring of chondrichthyan catches and fishing effort. In addition, a fundamental problem in the region is a limited knowledge of which cartilaginous species are being exploited, primarily because of the apparent inability of most fishermen and anglers to distinguish between even morphologically distinct species (Compagno et al. 2005a).

1.7.2. Fishing threats

South Africa has experienced a long history of fishing and the effects of exploitation on chondrichthyans include pressure from commercial, artisanal, subsistence and recreational fishing activities, as well as shark control programmes designed to reduce the risk of shark attack at bathing beaches (Stevens et al. 2000). Although interest in targeted fishing of chondrichthyans only began in the 1930s (Kroese et al. 1996), commercial fishing began as early as the 17th century (Penney 1991), and chondrichthyans would undoubtedly have been apart of their bycatch. For a more complete overview of cartilaginous catches and bycatches in South African fisheries see Kroese et al. (1996) and Da Silva and Burgener (2007).

Net-fishing

Beach seine fishing has essentially remained unchanged since the technique was introduced to South Africa during the mid-1600s (Lamberth 1994). By the early-1980s numerous management measures had been implemented, including reduction in overall netting effort, a restriction only allowing gillnetting on the West Coast, a permit system that required holders to submit daily catch returns, and numerous gear restrictions (Hutchings and Lamberth 2002). With the exception of False Bay, beach seine permits are now issued exclusively for the capture of harders (*Liza richardsoni*) and St. Joseph shark (*Callorhinchus capensis*). All other fish must be either returned to the water unharmed, or if dead, surrendered to the local authorities (Lamberth 1994).

Gillnets were introduced by Portuguese fisherman during the 1860s (Lamberth et al. 1997). However, a directed gillnet fishery in the Western Cape, also targeting St. Joseph shark, was not established until the early 1980s (Freer & Griffiths 1993). Despite requirements to submit daily returns, studies have shown catch records submitted by net-fishers to be inaccurate, with up to 90% of the effort and catch, particularly of bycatch species, not reported (Lamberth et al. 1994).

Linefishing

The Cape commercial linefishery, as we know it today, is boat-based and developed shortly after all fishing restrictions were removed by the British in 1795 (Griffiths 2000). By the mid-1800s the mobile linefishery had become a thriving industry and today comprises about 3 000 boats (Mann et al. 2000). In spite of this long history, the first comprehensive management framework for the South African linefishery was only introduced in 1985 (Penney et al.

1989). This framework included a requirement for owners of commercial lineboats to submit daily return of catch and effort to Marine and Coastal Management.

Linefishing effort was highest at the turn of the 19th century in the southwestern Cape (Cape Point to Cape Agulhas) and increase threefold by the 1930s. At the same time a shift toward motorized vessels was underway. The modern trailered skiboat, which increased operations through greater speeds at sea and the option of land-based boat transport, was introduced to the Cape from KwaZulu-Natal in the 1970s (Griffiths 2000). When commercial permits were issued in 1985, with the intention of capping fishing effort, virtually all applicants were successful, thus further driving stock declines (Griffiths 2000). It is estimated that chondrichthyans account for 1-2% of the total landed catch of the linefishery, of which the majority were soupfin shark, *Galeorhinus galeus* (Compagno et al. 2005a).

Demersal trawl

The South African otter-trawl fisheries are mainly located on the continental shelf along the coast from KwaZulu-Natal to Saldanha Bay, and some of the earliest grounds to be exploited in South Africa are in the Western Cape, first trawled in 1897 (Scott 1949). Today two major fisheries exist, targeting hake and inshore sole. Widely known for its large catch of non-target species—the inshore trawl has the second highest bycatch of any South African fishery—trawling impacts species from all trophic levels from the small benthic crustaceans to large chondrichthyan predators (Attwood et al. 2011). Through an observer programme, it was estimated almost 5 000 tonnes of chondrichthyans are caught in the South African fishery annually, with 56.4% of this being discarded (Compagno et al. 2005a).

Longline

In South Africa, the shark longline fishery originated in the post-WWII era among coastal communities targeting the soupfin shark (Freer 1992). Currently the longline fishery operates between Cape Town and Port Elizabeth (Da Silva & Burgener 2007). Effort began to decline after 1992 when restrictive legislation was introduced. Permits are now issued and the fishery comprises two methods of targeting sharks. The first uses bottom-set gear and targets soupfin and smooth-hound (*Mustelus* spp.) shark. The second uses drift gear in the offshore pelagic environment, targeting mako and blue sharks (Compagno et al. 2005a). In addition, pelagic longline fisheries targeting tunas and swordfish were developed in the 1970s and had a bycatch of pelagic sharks (Sauer et al. 2003). It is estimated that an average of approximately 43 000 pelagic shark were caught annually in South African longline fisheries for the period 1998-2005 (Petersen et al. 2009).

Recreational angling

Although shore angling in South Africa has been a popular pastime since the 1900s, only in the 1980s did catch data on a regional or national scale begin to be recorded (Bennett 1991). Teleosts are preferentially targeted, however, it was clear that historical catches were probably very different from those today. Van der Elst (1989) began documenting declines in many teleosts with a corresponding increase in the importance of cartilaginous species. The open access recreational fishery is large and growing with approximately 500 000 participants in 1996 (Mann et al. 2000). Today the recorded recreational shark competition catches vary between 28-77 tonnes annually, and although most are released it is unknown what proportions die as a result of angling stress and injuries (Compagno et al. 2005a).

Shark nets

In 1952, following a series of shark attacks in the South African city of Durban, 12 gillnets were installed along their beaches to reduce the probability of an encounter between shark and bather (Dudley & Simpfendorfer 2006). By 1994 there was a total of 41 km of netting, protecting bathers at around 64 beaches between Richards Bay and Mzamba (Dudley 1997). These nets achieve their protective function through reducing the populations of large sharks in the area (Dudley & Simpfendorfer 2006). In South Africa, on average, some 1 200 (85 t) chondrichthyans are caught in these nets, and a large proportion of the species caught are not considered to be dangerous to humans (Compagno et al. 2005a).

1.7.3. Current management and protection

South Africa is apart of broad agreements that include in their mandates to protect and conserve the environment. For example, South Africa is a member of the Southern African Development Community that requires State Parties to achieve sustainable utilisation of natural resources and effective protection of the environment (SADC 1997). Likewise, the Marine Living Resources Act (MLRA), enacted by South Africa in 1998, includes as objectives to achieve ecologically sustainable development of marine resources, to conserve marine resources for the present and future and to apply precautionary approaches toward the management and development of marine resources (Government Gazette 1998). Specifically, the MLRA prohibits the catch or possession of the white shark, basking shark, whale shark and sawfishes (Pristidae spp.). In addition, under this legislation, linefisheries are limited to a catch and possession limit of one shark per day of listed species, which include most chondrichthyans (Rose 1996). Finally, a working group was established in 2001 to produce a Shark Assessment Report and National Plan of Action (NPOA) for chondrichthyans in South Africa under the FOA's IPOA-Sharks. Although drafted in 2003, the NPOA is still awaiting government approval (Compagno et al. 2005a). This lack of implementation suggests some hesitancy in the management and conservation of cartilaginous species.

On one hand, with the exception of a few restrictions, such as banning pelagic gillnets; the use of permits and limited entry (though without quotas) for longlining and gillnetting; and a ban on the finning of sharks in national waters (Compagno et al. 2005a; Fowler et al. 2005), few controls are in place to limit the harvest of all chondrichthyans in South Africa (Da Silva & Burgener 2007). By and large, whether caught as bycatch or as targeted species, enforcement of such regulations is poor (Compagno et al. 2005a). On the other hand, South Africa has a network of 22 Marine Protected Areas (MPAs) along its coastline that incorporates a range of management types from multi-purpose MPAs to no-take zones (Tunley 2009). Though MPAs were not developed to protect chondrichthyans specifically, it is likely that they benefit those species that remain within them.

CHAPTER 2.

CHONDRICHTHYAN EXPLOITATION IN THE 20TH CENTURY

2.1. Introduction

People have congregated along coastlines from the start of humanity. At present around 40% of the world's human population lives within 100 km of the coast, and this is expected to rise (Martinez et al. 2007). The cumulative effects of exploitation, habitat destruction, and pollution are more severe in estuaries and coastal seas than anywhere else in the ocean (Jackson 2008). As a result of this human pressure there is broad concern for coastal conservation around the world (Suchanek 1994). False Bay, South Africa is an example of this trend (Spargo 1991; Yeld 2008).

False Bay was chosen as the study site for a few reasons. Firstly, it is the largest true bay in South Africa with a heavily populated shoreline (Spargo 1991). The increase in population corresponds with the increase in exploitation and use of False Bay. Secondly, with an increase in utilisation there exists a range of human pressures, such as fishing, pollution, habitat modification and recreation that negatively impact the system (Stevens et al. 2005).

Thirdly, on one hand, False Bay has one of the longest histories of commercial exploitation dating back to the 17th century (Penney 1991), as well as experiencing all major fishing methods. On the other hand, however, False Bay has had the longest protection from trawling (Scott 1949). This effectively protects all deep-water habitats from exploitation, making False Bay one of the more intact areas around the South African coast. Additionally, multiple marine reserves along its shores—the first reserve was established in 1938 (Spargo 1991)—provides further protection from direct exploitation. The synergistic effects among harvesting, habitat changes and climate-induced forcing are greatest for coastal chondrichthyans with specific habitat requirements and these are currently the most likely candidates for extinction (Field et al. 2009).

Fourthly, because chondrichthyans are a broad group of predators they represent almost all trophic levels above herbivore for each of the major ecosystem types in False Bay. Of the roughly 180 chondrichthyan species in Southern African waters (Smith & Heemstra 1986), it is estimated that approximately 40 occur in False Bay alone. Assuming top predators maintain ecosystem structure and function, the 'health' of chondrichthyan populations should correspond with the 'health' of an ecosystem or food chain. The removal of such top-down control, through fishing, negatively affects ecosystem structure and function (Jackson 2008).

Finally, the threat of shark attack is a concern in False Bay, which has witnessed approximately six attacks in the last decade (A. Kock pers. comm.). A spate of shark attacks would quickly incite public demand for the implementation of shark nets such as those used in KwaZulu-Natal (Dudley & Simpfendorf 2006), which could further reduce vulnerable chondrichthyan populations. Due to the importance of chondrichthyans in the ecosystem any population loss caused by potential implementation of shark nets would see a cascade of impacts throughout the Bay (Stevens et al. 2005). These nets have been shown to impact not only the target species populations, but also impact non-target species, like smaller cartilaginous species, seabirds, cetacean and sea turtles (Dudley & Simpfendorf 2006). Chondrichthyans are therefore seen as an indicator of ecosystem health in False Bay.

Although there is concern over chondrichthyan exploitation, stemming from consideration of their biological and ecological traits and from historical exploitation patterns, protection of these species from the impacts of fisheries is not impossible. Bonfil (1994) suggests that to properly assess the current state of sharks and their relatives, it is essential to increase knowledge of the diversity in the respective fisheries, the species exploited, the size of the catches, and harvesting practices. Only through this improved knowledge can there be effective management and protection of chondrichthyans. Therefore, a consolidation of all available fishing and survey data are needed to describe this community and its changes over the last 100 years, and to assess their vulnerability to present and future threats.

2.1.1. Aim of the study

In this thesis, I intend to compile and analyse all available historical and current data on the occurrence, distribution and exploitation of chondrichthyans in False Bay, South Africa. This combined information will serve as a population baseline for chondrichthyans in False Bay and provide a means for assessments of conservation status of select taxa.

To achieve these objectives the following key questions were asked:

1. Which chondrichthyan species have historically occurred and still occur in False Bay, and in what proportions?
2. Has there been a shift in the patterns of exploitation of chondrichthyans in False Bay over the 20^{th} century?
3. Is there evidence of a change in the relative abundance of chondrichthyans over the 20^{th} century?
4. Can we predict the conservation status of chondrichthyans on the basis of life history parameters?

2.2. Materials and Methods

2.2.1. Study area

False Bay (34°04' - 34°23'S, 18°26' - 18°51'E), in the southwestern Cape (Fig. 1), is a very large bay, measuring over 1 600 square km and 90 m at its deepest point (Cliff 1982). Its mouth opens south to the Atlantic Ocean, is 32 km wide and lies between Cape Point and Cape Hangklip. This is in an area of overlap of the cold Benguela Current and the warmer Agulhas Current, and as a result contains a mixture of species from the cold-temperature west coast fauna and the warm-temperature south coast fauna (Cliff 1982). Day et al. (1970) have recorded over 200 species of fish in the Bay, 41% of which are endemic to South Africa, and are spread across four major habitat types: rocky reef, sandy bottom, deep unconsolidated sediments or mud, and surf zone (Day 1970). Day (1970) and Spargo (1991) provide a more detailed description of the Bay's physical environment.

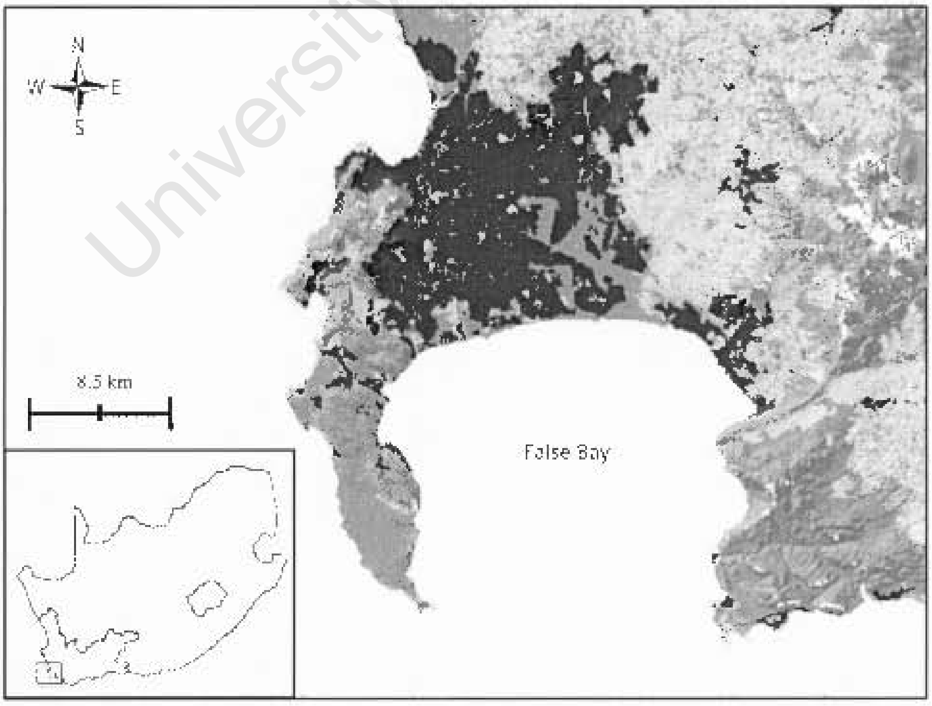

Figure 1. South Africa, the Western Cape (primary inset) and False Bay, South Africa.

False Bay has had a long history of exploitation involving many fishing methods—commercial exploitation beginning as early as the 17th century (Penney 1991). Beach seining started on False Bay shores not long after the first ship arrived in Cape Town in 1652. By the 1960s there were well over 100 commercial beach seine operators in False Bay, however effort was reduced to only seven operators in 1990 (Lamberth 1994). Demersal trawling began in False Bay at the end of the 19th century, although much of the bottom is rough and unsuitable for trawling (Day 1970), and continued for 30 years before the grounds were closed in 1928 to protect inshore fisheries (Scott 1949). From a commercial fisheries perspective False Bay is not as productive an area as the west coast (Day 1970). Over the course of the 20th century the small scale line-boat fishery operating from Kalk Bay was the most lucrative fishery (Penney 1991). In addition to the established linefish industry, False Bay has long been recognized as an excellent angling destination, and an important tourist attraction, with a wide variety of reef fish all year round and migratory predators such as geelbek (*Atractoscion aequidens*) and yellowtail (*Seriola lalandi*) in summer (Day 1970).

2.2.2. Data collection

Historical and contemporary fisheries records were compiled to reconstruct the history of chondrichthyan exploitation and to evaluate trends in population abundance in False Bay during the 20th century. Different sources of information, including commercial and recreational fisheries landings, scientific surveys and underwater records were used to assemble time series of abundance data intermittently from 1897 to 2011. The subsequent fishing or sampling methods were trawl surveys, demersal longline catch returns, commercial linefish catch returns, beach seine scientific surveys and commercial catch returns, recreational angling, SCUBA diving underwater census, spearfishing and rotenone (poison) surveys (Appendix I). Historical trawl survey records from False Bay were extracted from the

Director of Fisheries, Marine Biological Survey Reports (Appendix I). Demersal longline data were provided by C. Da Silva, Department of Agriculture, Forestry and Fisheries. Commercial linefish data were extracted from the National Marine Linefish System (Penney 1994; Penney et al. 1997), a database containing commercial catch return records from 1985-2010. Beach seine data were provided by S. J. Lamberth, Department of Agriculture, Forestry and Fisheries, and survey records were extracted from published sources (Lamberth et al. 1995; Clark et al. 1996). Recreational angling records were collected from unpublished club records and provided by Thys Kemp from the Western Cape Shore Angling Association. Lastly, SCUBA census (Cliff 1983; Lechanteur 1999; Lechanteur & Griffiths 2001) and poison surveys (Prochazka 1998), as well as spearfishing records (Lechanteur 1999), were also found in published literature. The time periods represented (Fig. 2) and the quality and quantity of data varied considerably. For this reason, not all data sets could be analysed using a standard protocol.

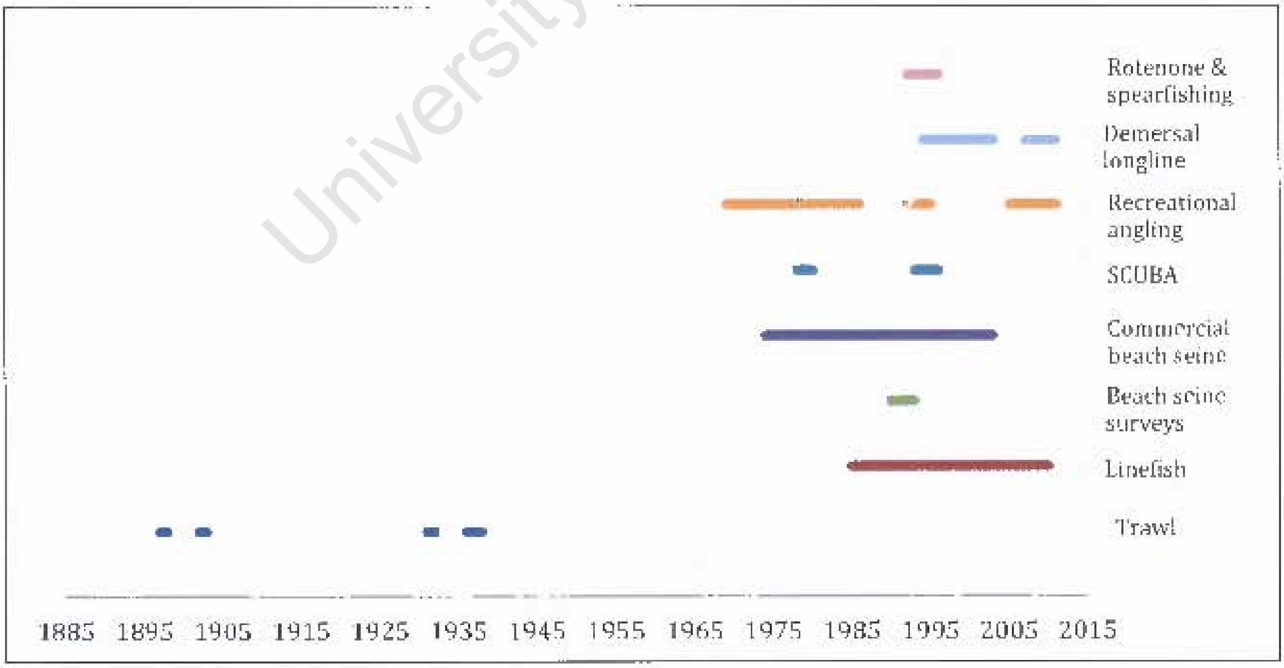

Figure 2. Time periods for which various data sources were available from False Bay to assess chondrichthyan exploitation over the 20th century.

2.2.3. Data analysis

Data were analysed for trends both within and between fishing methods. Due to variable taxonomic resolution of certain data sets (e.g. linefish and commercial beach seine catches) some species were grouped according to family for analysis. In other instances, higher taxonomic groups were distributed proportionately between appropriate species (e.g. linefish). Various metrics were used to assess the extent of exploitation of various chondrichthyan species in each of the major fishing methods. These metrics were catch, relative species catch and catch per unit effort (CPUE). The annual proportion of all chondrichthyans combined relative to the total catch, as well as, annual species-specific proportions were calculated for the majority of fishing methods. In addition, the mean and standard deviation of the annual catch (in numbers of individuals) for cartilaginous species were calculated for the major fishing method as a measure of the magnitude of catch.

All multivariate analyses were performed in PRIMER analytical package (Clarke 1993) using standardized and fourth-root transformed data to reduce the influence of abundant teleost species. Cluster analyses were preformed using the Bray-Curtis index of similarity and the group-average method of linkage. These relationships were further investigated using multi-dimensional scaling (MDS) to produce a two-dimensional representation of the relationships between samples. Also, clustering and ordination techniques were used to illustrate the degree of similarity in the species composition of catches from different methods across time. Finally, where effort data were available, annual CPUE (individuals per number of samples) for the most commonly caught species were calculated for the fishing methods with the longest time series: commercial linefishing, commercial beach seining, recreational angling and commercial demersal longlining.

Comparability of data sources

Using PRIMER, cluster and ordination techniques were used to analyse the similarities between methods and were displayed on a dendrogram and ordination plot, respectively. DIVERSE and SIMPER analyses were performed among fishing methods on the relative composition of all species (Appendix II) to describe the diversity of catches per method and the similarity among methods. The Shannon Index and total species count from each fishing method in the diversity analysis were plotted and those methods with the highest values were chosen for further analysis.

Analysis of commercial linefish catch returns

Commercial linefishery catch return data from False Bay were extracted from the National Marine Linefish System (NMLS) database, which has species catch recorded in kilograms per boat trip. Catch was converted to number of individuals using an average individual weight (Appendix III). In most cases catch was recorded to the species level, however, general categories such as 'Redfish', 'Shark' and 'Rays' were also present, causing some species to be double-listed.

Using data from all trips in False Bay, the annual catch for all chondrichthyans combined and the proportion of cartilaginous species in total catch were calculated. Annual mean CPUE was calculated as the mean number of individuals caught per species per boat trip per day. A problem developed within the data due to the targeting of particular species; as a result it was unclear if a zero in the data for a cartilaginous species was a true absence or simply not a target species. To clarify this issue a multivariate analysis using the CLUSTER and MDS programs in PRIMER, and the protocol described above, was run to determine the similarity among species based on their representation in fishing trips. Various species complexes produced were identified as separate targets. When calculating CPUE for a particular species, only records that included one of these species in the target group were used (Pelletier & Ferraris 2000). To correct for the double-listing of species a formula was used to split the quantity in a higher order taxonomic level into various species components under that taxon as follows:

$$CPUE_{x,y}^{a} = CPUE_{x,y} + CPUE_{g,y} * \frac{CPUE_{x,y}}{\sum_{i=1}^{n} i,y} \qquad \text{Eq. 1}$$

when $CPUE_{x,y}^{a}$ is the adjusted CPUE in year y of species x, $CPUE_{x,y}$ is the nominal CPUE in year y of species x, $CPUE_{g,y}$ is the CPUE calculated on the volume of fish lumped in higher order taxon g, and $\sum_{i=1}^{n} CPUE_{i,y}$ is the sum of the CPUE of all species that fall within taxon g. Finally, the annual fishing threat to chondrichthyans by commercial linefishing was calculated as the annual effort directed at the 'shark complex'. This was done using the annual sum of boat trips that caught one of the species in the chondrichthyan species complex.

Analysis of beach seine catch returns

Data on beach seining activities in False Bay were divided into commercial seines (1974-2003) and scientific surveys (1990-1993), and analysed separately. Surveys reported every species captured, whereas commercial seining often lumped species into general categories like 'Shark', 'Ray' and 'Fish'. Species catch and the proportion of cartilaginous fish in the catch were calculated for both commercial- and survey-seining. A PRIMER similarity (ANOSIM) analysis was run comparing commercial and survey beach seining, in 1991 and 1992, to test the significance of observed differences between data sets to determine if they were comparable. Two chondrichthyan species that were well represented in the commercial catch records had CPUE calculated for each. The survey data set, however, was too brief to produce useful abundance variation over time and CPUE was not calculated.

Analysis of recreational angling catch records

To identify trends in recreational angling, data from all club records were combined to form an extensive data set, running from 1967 until 2011, with only one significant gap from 1996 to 2004. Annual catch and cartilaginous proportion of total catch were calculated. To examine trends in species composition over time, mean annual species composition was analysed in a CLUSTER analysis. Principle components analysis (PCA) was used to extract the first two principle components (PC1 and PC2). PC1 was regressed against year. Although catch effort was not provided for all club records, and therefore CPUE could not be generated, trends in individual species were analysed by the proportion of total catch caught by anglers.

Analysis of demersal longline catch return

Commercial demersal longline records from 1992 to 2011, excluding 1993 and 2004-2006, were used to investigate catch trends. To do this, total annual catch and effort (number of hooks) for all chondrichthyan species were examined, as well as quantifying individual species trends using CPUE. However, effort was not provided for the years 1994 and 1995, and was therefore left out of effort and CPUE analyses.

Analysis of historical trawl surveys

One hundred and forty-four survey trawls, spread intermittently between 1897 and 1932, were analysed for catch trends in four species and five genera. The minimum sample size was three trawls in 1927. Annual mean CPUE was calculated for each taxon.

Trend analysis

Trends in the absolute catch per unit effort of all chondrichthyans combined were tested using simple linear regression procedure (Zar 1984) for commercial beach seine, commercial linefishing, and demersal longline. CPUE data were not available for recreational angling. Instead, the proportion of chondrichthyans in the total recreational catch was analysed for a temporal trend using simple linear regression.

Species-specific trends in abundance indices for each of the primary fishing methods (commercial linefish, commercial beach seine, recreational angling, demersal longling and trawl) were analysed using a rank correlation for annual CPUE or catch proportion (recreational angling) data. Again recreational angling data yielded relative proportion of the catch. Rank correlation was used in preference to simple linear regression because the dependent variable was seldom normally distributed and usually included a high frequency of zeros. The rank correlation procedure is considered more robust. Rank correlation was used even in cases where the parametric correlation could be used – in these cases the rank correlation is approximately 91% as powerful as the parametric correlation (Zar 1984).

It was expected that the information content of the abundance indices would be low for some or all fishing methods because of problems with species identification and quality of reporting. For this reason it was deemed necessary for each particular species to search for agreement in trends across the four methods. Agreement across the methods was deemed to have occurred in either of the following two cases:

(i) If a trend was detected with $p<0.01$ for at least one method in which the species was a substantial part of the catch, and no opposing trend being detected by any other method.

(ii) If a trend was detected with $p<0.1$ in at least two methods with no opposing trend from any other method.

2.2.4. Vulnerability assessment

Life history characteristics for the majority of the species were used to determine an index of productivity or resilience using any or all parameters defined by Musick (1999b): intrinsic rate of population increase (*r*), von Bertalanffy k, fecundity, age at maturity, and maximum age. Each species was allocated to one of four productivity categories (very-low, low, medium, or high) using the corresponding value ranges for each parameter given in Musick (1999b). In addition to population productivity, the following criteria were also taken under consideration when evaluating risk of chondrichthyan fishes to significant population reduction: small population, habitat requirements, small range or endemicity, mortality threat associated with habitat, and population decline. Evaluating the aforementioned risk criteria identified species populations that were *stable, vulnerable, threatened*, of *conservation concern* or had *unknown* exploitation status in False Bay, thus identifying those species in need of monitoring, conservation management or protection.

2.3. Results

2.3.1. Chondrichthyan catch trend analysis

Sample size

The three longest time series were commercial beach seine returns, commercial linefish returns, and recreational angling records which listed 27 150 338, 13 297 523, and 23 752 fish, respectively. Two similarly productive sampling techniques were the beach seine surveys and trawl surveys, but these times series were comparatively brief, and provided only 85 500 and 109 077 fish, respectively. Demersal longlining for chondrichthyans in False Bay has been a relatively recent and heavily restricted fishery, which has yielded only 12 612 fish. Longlining is the only fishing method aimed exclusively at chondrichthyans – although teleosts may have been caught they were not recorded. Among the other time series data the percentage of chondrichthyans by number in the samples ranged from 0.02% in commercial beach seine to 30.7% in recreational angling. The three shortest time series were the underwater methods namely SCUBA, spearfishing and poisoning which listed 4 842, 1 174 and 1 199 fish, respectively.

Species diversity and composition

Records from all sources combined revealed 38 chondrichthyan species caught and/or sighted at least once in False Bay (Table 1). The five most commonly caught species were *Galeorhinus galeus* (soupfin shark) with 25 085 recorded individuals, *Mustelus mustelus* (smooth-hound shark) with 18 087, *Rhinobatos annulatus* (lesser guitarfish) 6 386 individuals, *Callorhinchus capensis* (St. Joseph shark) 4 545, and *Notorynchus cepedianus* (broadnose sevengill or cow shark) with 3 705 individuals reported.

Table 1. Chondrichthyan species recorded in the nine sampling methods in False Bay in the 20^{th} century and their current conservation status and population trend globally.

Family	Species	Common Name	IUCN Status[a]	Population Trend[b]
Hexanchidae	*Notorynchus cepedianus*	Broadnose sevengill	DD	Unknown
Dalatiidae	*Etmopterus granulosus*	Southern lantern shark	LC	Unknown
Squalidae	*Squalus acanthias*	Spotted spiny dogfish	LC	Decreasing
Squalidae	*Squalus megalops*	Bluntnose spiny dogfish	DD	Unknown
Carcharhinidae	*Carcharhinus brachyurus*	Copper shark	NT[c]	Unknown
Carcharhinidae	*Carcharhinus brevipinna*	Spinner shark	NT	Unknown
Carcharhinidae	*Carcharhinus limbatus*	Blacktip shark	NT	Unknown
Carcharhinidae	*Prionace glauca*	Blue shark	NT	Unknown
Traikidae	*Galeorhinus galeus*	Soupfin shark	V	Decreasing
Traikidae	*Mustelus mustelus*	Smooth-hound shark	V	Decreasing
Traikidae	*Triakis megalopterus*	Spotted gullyshark	NT	Unknown
Scyliorhinidae	*Halaelurus natalensis*	Tiger catshark	DD	Unknown
Scyliorhinidae	*Haploblepharus edwardsii*	Puffadder shyshark	NT	Unknown
Scyliorhinidae	*Haploblepharus pictus*	Dark shyshark	LC	Unknown
Scyliorhinidae	*Poroderma africanum*	Striped catshark	NT	Unknown
Scyliorhinidae	*Poroderma pantherinum*	Leopard catshark	DD	Unknown
Scyliorhinidae	*Scyliorhinus capensis*	Yellowspotted catshark	NT	Unknown
Sphyrnidae	*Sphyrna zygaena*	Smooth hammerhead	V	Decreasing
Lamnidae	*Carcharodon carcharias*	Great white shark	V	Unknown
Lamnidae	*Isurus oxyrinchus*	Shortfin mako	V	Decreasing
Alopiidae	*Alopias vulpinus*	Thintail thresher shark	V	Decreasing
Odontaspididae	*Carcharias taurus*	Spotted ragged-tooth	V	Unknown
Pristiophoridae	*Pliotrema warreni*	Sixgill sawshark	NT	Unknown
Torpedinidae	*Torpedo fuscomaculata*	Blackspotted electric ray	DD	Unknown
Torpedinidae	*Torpedo marmorata*	Marbled electric ray	DD	Unknown
Narkidae	*Narke capensis*	Onefin electric ray	DD	Unknown
Rajidae	*Rostroraja alba*	Spearnose skate	E	Decreasing
Rajidae	*Raja clavata*	Thornback skate	NT	Decreasing
Rajidae	*Raja miraletus*	Twineye skate	LC	Stable
Rajidae	*Raja straeleni*	Biscuit skate	DD[c]	Unknown
Rhinobatidae	*Rhinobatos annulatus*	Lesser guitarfish	LC	Unknown
Myliobatidae	*Myliobatis aquila*	Eagleray	DD[c]	Unknown

Myliobatidae	*Pteromylaeus bovinus*	Bullray	DD[c]	Unknown
Dasyatidae	*Dasyatis brevicaudata*	Short-tail stingray	LC	Unknown
Dasyatidae	*Dasyatis chrysonota*	Blue stingray	LC	Unknown
Dasyatidae	*Dasyatis thetidis*	Thorntail stingray	DD	Unknown
Dasyatidae	*Gymnura natalensis*	Diamond ray	DD[c]	Unknown
Callorhinchidae	*Callorhinchus capensis*	St. Joseph shark	LC	Stable

[a]Current species status worldwide, taken from the IUCN Red List. Categories: DD (data deficient); LC (least concern); NT (near threatened); V (vulnerable); E (endangered); and CR (critically endangered).
[b]Population trends taken from the IUCN Red List species assessment
[c]Least Concern in South Africa

Survey beach seine, commercial linefishing and recreational angling yielded the highest species diversity with 95, 77 and 65 fish species, respectively. A diversity analysis of only chondrichthyan species found recreational angling, survey beach seine and commercial linefishing to be the highest in terms of species number with 24, 19 and 17 respective species, and species richness (Fig. 3). These three methods had the highest alpha diversity and evenness (Shannon Index) and provided the broadest spectrum of information on teleost and chondrichthyan communities.

Before discarding those methods with low diversity and/or high selectivity it was necessary to check which, if any, species were uniquely recorded by any method. *Etmopterus granulosus* (southern lantern shark), *Pliotrema warreni* (sixgill sawshark) and *Squalus acanthias* (spotted spiny dogfish) were recorded in trawls only. However, *S. acanthias* may well have been caught in another fishing method and either confused with the more common *S. megalops* or simply lumped into the *Squalus* spp. category. All other rarely recorded species were recorded in the combination of commercial linefishing, recreational angling and beach seine survey.

Species that were frequently lumped at the generic level in certain time series (mostly commercial linefish and commercial beach seine) included *Raja* spp. (skates), *Poroderma* spp. (catsharks), *Torpedo* spp. (electric rays), and *Squalus* spp. (dogfish). Fortunately these data sets gave sufficient listings of these chondrichtyans at the species level as well, allowing for their disaggregation using Equation 1, but some uncertainty remains on the precise proportions of these species.

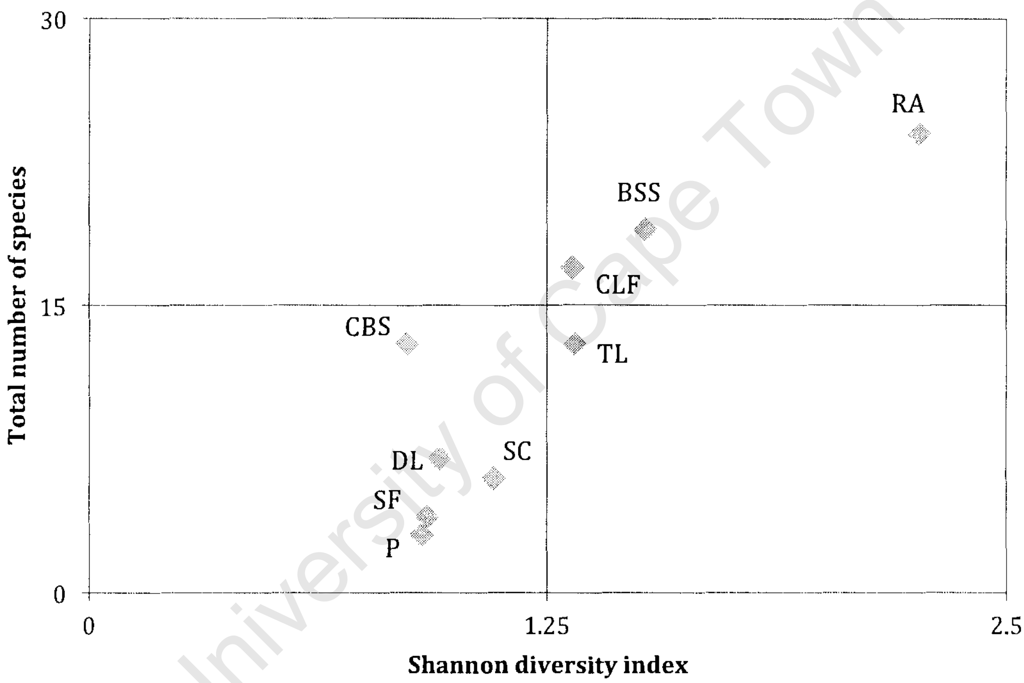

Figure 3. Chondrichthyan alpha diversity and evenness between nine fishing methods in False Bay, South Africa. RA (recreational angling), BSS (beach seine survey), CLF (commercial linefish), TL (trawl), CBS (commercial beach seine), DL (demersal longline), SC (SCUBA diving), SF (spearfishing), and P (poison).

Several chondrichthyan species were recorded in the False Bay samples, which according to previous records suggest that their presence here was extralimital. In 1929, *E. granulosus* was recorded in a trawl in approximately 30 m depth, although its presence had been recorded as occurring between 336 to 1 464 m off the southwestern Cape, and off the coast of South America (Smith & Heemstra 1986). *Raja straeleni* (Biscuit skate), first recorded in 1980 in a False Bay beach seine net, is on the eastern edge of its listed range off Namibia and west coast (Smith & Heemstra 1986). Those species that have been recorded west of their range include *Carcharhinus brevipinna* (spinner shark) in commercial linefish catch from 1997, 2005, 2007 and 2008; *Torpedo fuscomaculata* (blackspotted electric ray) from a beach seine survey in 1992; *Dasyatis thetidis* (thorntail stingray) from recreational angling catch in 1989 and 2010; and *Gymnura natalensis* (diamond ray) from commercial beach seine catch in 1979, 1991 and 1992, and regularly caught by recreational anglers between 1982-2011. These species were previously listed as occurring eastwards of Mossel Bay, Knysna, Algoa Bay, and Mossel Bay, respectively (Smith & Heemstra 1986).

Of all the chondrichthyans recorded in False Bay, 14 species (37%) were considered to be of primarily Atlantic origin and seven species (18%) were predominately from the Indo-Pacific region (Smith & Heemstra 1986; Compagno et al. 2005b). Of the chondrichthyans with restricted distributions eight (21%) were endemic to Southern Africa and four (11%) to South Africa. The remaining five species (13%) were cosmopolitan pelagic sharks found across the world. Nine species (24%) found in False Bay almost entirely persist in water less than 100 m. However, the majority (27 species, 71%) regularly occur from the shallows to depths far exceeding 100 m. Only two species are primarily found only in water deeper than 100 m (Smith & Heemstra 1986; Compagno et al. 2005b) although False Bay is 90 m at its deepest point.

The prevalence of each species in the various types of data differs markedly (Appendix II). However, the shape of the species dominance curves for methods with the highest diversity were similar. Commercial linefish returns, recreational angling and beach seine, for example, each had five cartilaginous species that constituted between 73 and 98% of the total chondrichthyan catch. In contrast an average of 15 species in each case made up less than 1% of the total chondrichthyan catch. The most common species for each method, however, had only moderate overlap. These were, in order of prevalence, from commercial linefish: *Triakis megalopterus* (spotted gully shark), *Squalus megalops* (bluntnose spiny dogfish), *N. cepedianus, M. mustelus,* and *G. galeus*. The most common from beach seine surveys included: *R. annulatus, C. capensis, Myliobatis aquila* (eagle ray), *M. mustelus*, and *Dasyatis chrysonota* (blue stingray); and from recreational angling: *G. galeus, D. chrysonota, R. annulatus, Carcharhinus brachyurus* (copper shark), and *T. megalopterus*.

The analysis of similarity among methods based on the relative quantities of all fish species (Super Class Gnathostomata – cartilaginous, teleost and agnathans) revealed four groups of methods at 25% similarity (Fig. 4a). When similarity was increased to 35% the methods formed six groups according to the sampling technique. These groups showed affinities primarily on the basis of gear or techniques. For example, the two angling methods group together, the two underwater methods group together, and the net-based methods form two closely related clusters. The unique composition of demersal longline (entirely cartilaginous species) and poison (cryptic species unlikely to be capture by other methods) are positioned independently away from the primary methods.

The analysis of similarity among methods based on the quantities of chondrichthyans only, yielded different groupings (Fig. 4b). At 50% similarity recreational angling grouped most closely with beach seine surveys, but not commercial surveys, despite the similarity in the method and habitat of the two net-based methods. In another group, commercial linefish and demersal longline were closely associated, whereas spearfishing was more distant. The selectivity of spearfishing is probably what differentiated it from the third group that included the two subsurface sampling methods, SCUBA and poison, which included predominantly cryptic, non-marketable and non-edible chondrichthyans.

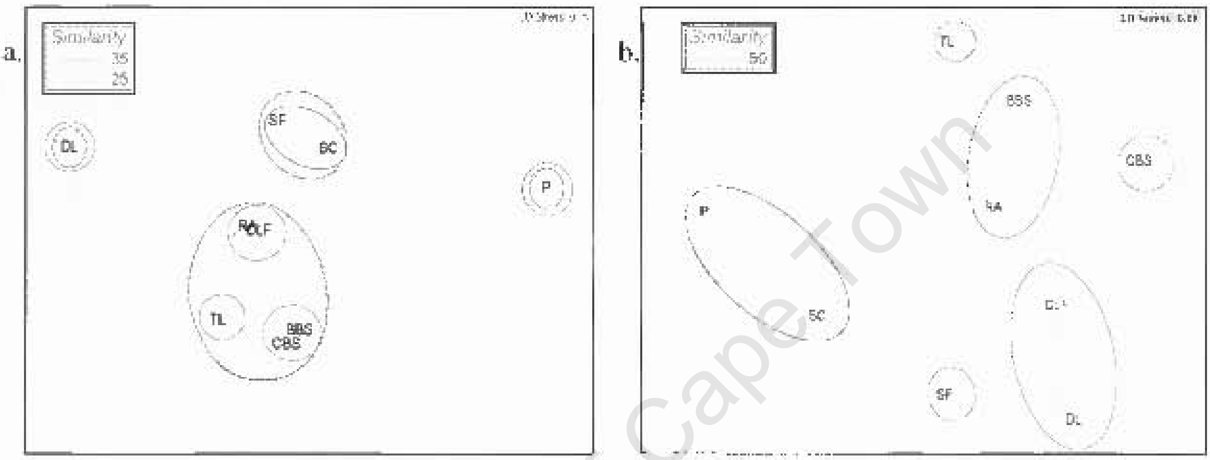

Figure 4. Multi-dimensional scaling (MDS) analysis of all fish species composition (a) and chondrichthyan composition (b) similarity between nine fishing methods occurring in False Bay, South Africa. BSS, beach seine survey; CBS, commercial beach seine; CLF, commercial linefish; DL, demersal longline; P, poison; RA, recreational angling; SC, SCUBA; SF, spearfishing; TL, trawl.

Analysis of commercial linefish catch returns

From the inception of the NMLS recording system until 2008, the effort in the False Bay commercial linefishery showed a fairly steady decline from 14 042 boat-trips to 1 140 boat-trips, although the linefishery showed a slight recovery in the last two years of the time series. The NMLS recorded 179 197 boat-trips in total from False Bay. The proportion of chondrichthyans in the total commercial linefish catch increased considerably after 2005, and reached a peak proportion of 0.09 cartilaginous fish in 2008, but declined again to the long-term average of around 0.01 in 2010 (Fig. 5). The years 2006-2009 represent an anomalous period during which the principle target of the linefishery, *Thyrsites atun* (snoek) yielded the lowest catches on record. The relative increase in chondrichthyans is not only an artefact of the disappearance of the principle target, but primarily reflects a shift in targeting towards chondrichthyans in that period. The increase in total catch of chondrichthyans exceeded the increase in the CPUE of all chondrichthyans, which indicates that more boats were shifting towards a cartilaginous target (Fig. 6).

In contrast, at the peak of the linefish catch in 1988, the proportion of chondrichthyans in the catch was insignificant. Long-term trends in commercial linefish CPUE of all chondrichthyans indicate an increase from a mean of 0.03 individuals per boat trip per annum in 1988 to 6.2 individuals per boat trip in 2008 (Fig. 6).

$$CPUE = 0.098 \times YEAR - 194.9, R^2 = 0.31, p = 0.002 \qquad \text{Eq. 2}$$

Chondrichthyan catch showed a peak in 1993 (Fig. 6), but this is difficult to interpret without correcting for targeting. Associations among cartilginous species overall were relatively low, however, a MDS analysis revealed a few shark species that grouped together on the basis of their co-occurrence in catches per boat trip, and would likely be caught or targeted together. They were: *M. mustelus*, *N. cepedianus*, *G. galeus*, *Squalus* spp., *T. megalopterus*, *C. brachyurus*, and *Sphyrna zygaena* (smooth hammerhead) (Fig. 7). This species complex, excluding dogfishes and hammerheads because they were caught so infrequently, were also the species most likely to makeup the unidentified 'shark' category.

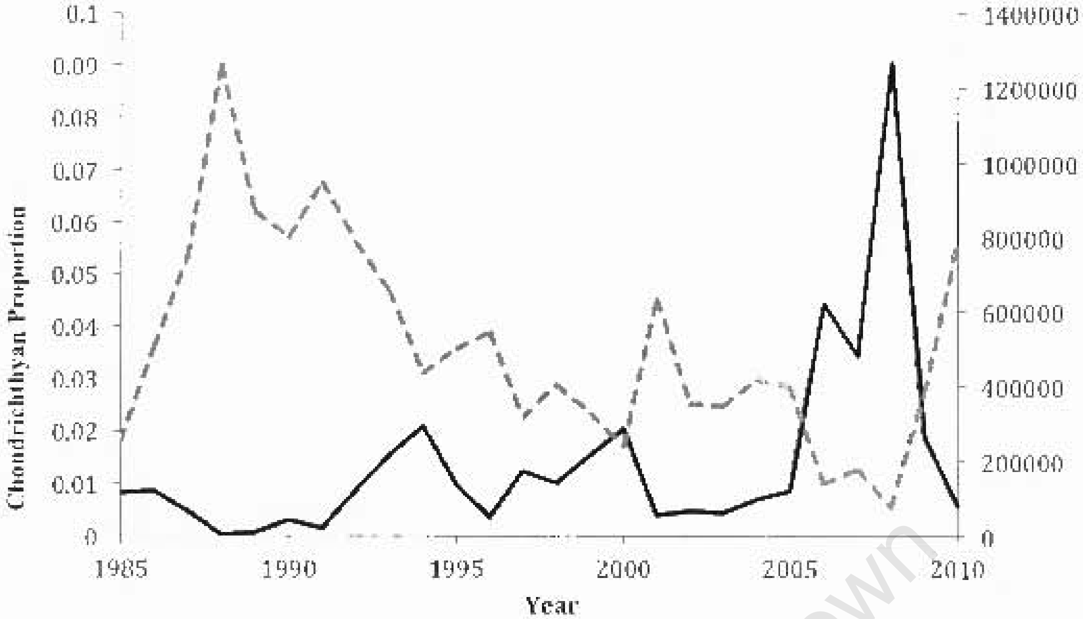

Figure 5. Commercial linefishery catch trends between 1985-2010. Cartilaginous proportion (solid line) and total catch by number of all fish species caught in False Bay (dotted line).

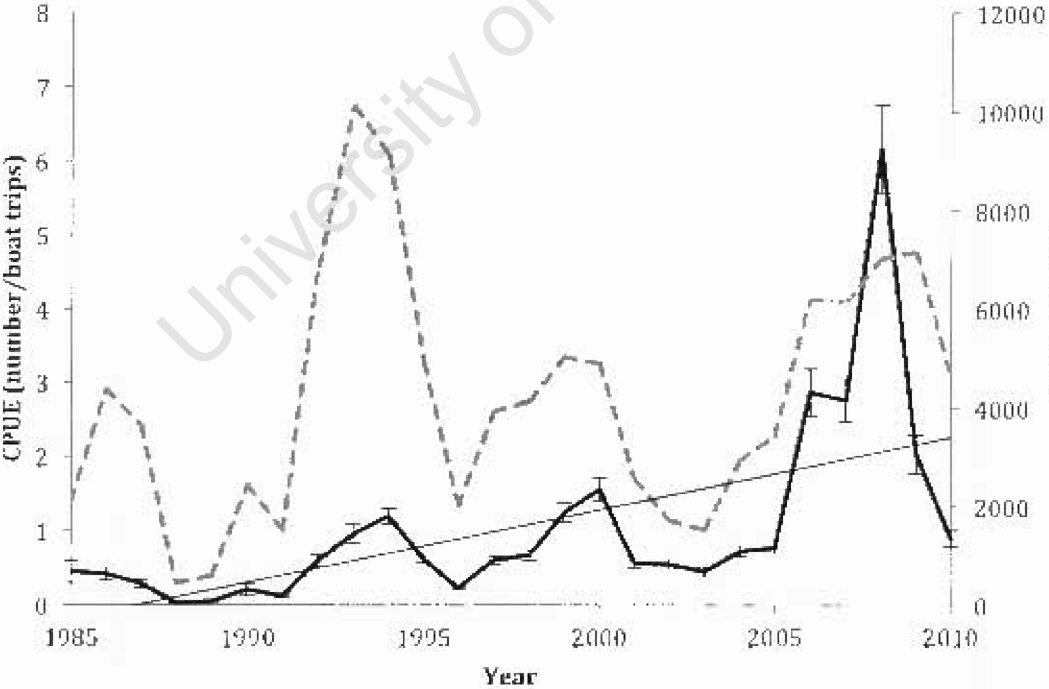

Figure 6. Mean catch per unit effort (CPUE) (solid line) and annual chondrichthyan catch in the False Bay commercial linefishery between 1985 and 2010 (dotted line). The straight line is the best-fit linear regression ($CPUE = 0.098 \times YEAR - 194.9$).

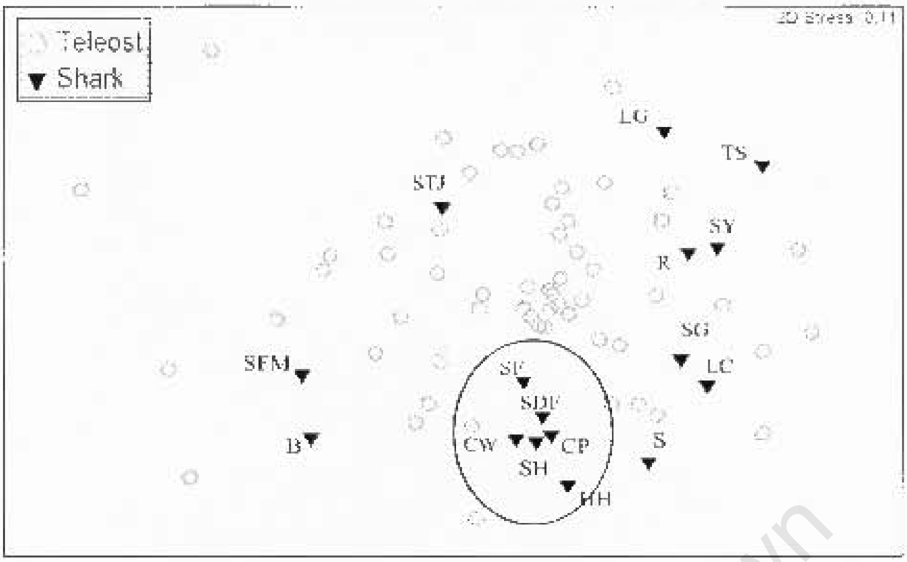

Figure 7. Multi-dimensional scaling (MDS) plot of commercial linefish calculated on the basis of their co-occurrence in catches of individual boat trips, showing the main chondrichthyan species complex (large circle). B (blue shark), CP (copper sharks), CW (cow shark), HH (smooth hammerhead), LC (leopard catshark), LG (lesser guitarfish), R (ray), S (spinner shark), SDF (spiny dogfish), SF (soupfin), SFM (shortfin mako), SG (spotted gully shark), SH (smooth-hound), STJ (St. joseph shark), SY (shysharks), TS (thresher shark). Teleost species (open circles) are not labelled.

The chondrichthyan species composition taken in the linefishery has changed over time and a shift in primary target species is clear. In 1985, *G. galeus* made up 95% of the reported chondrichthyan catch but over the last 15 years of the time series the proportion declined steadily, contributing just over 7% of the chondrichthyan catch in 2010. At the same time the proportion of *M. mustelus* increased, averaging over 40% of the chondrichthyan catch (Fig. 8). The combined proportions of the remaining cartilaginous species in the linefishery catch have also fluctuated over time, ranging from 0.01% to 40.9% of the total chondrichthyan catch. However, overall, the proportion of all other chondrichthyans remained low, averaging 13% annually.

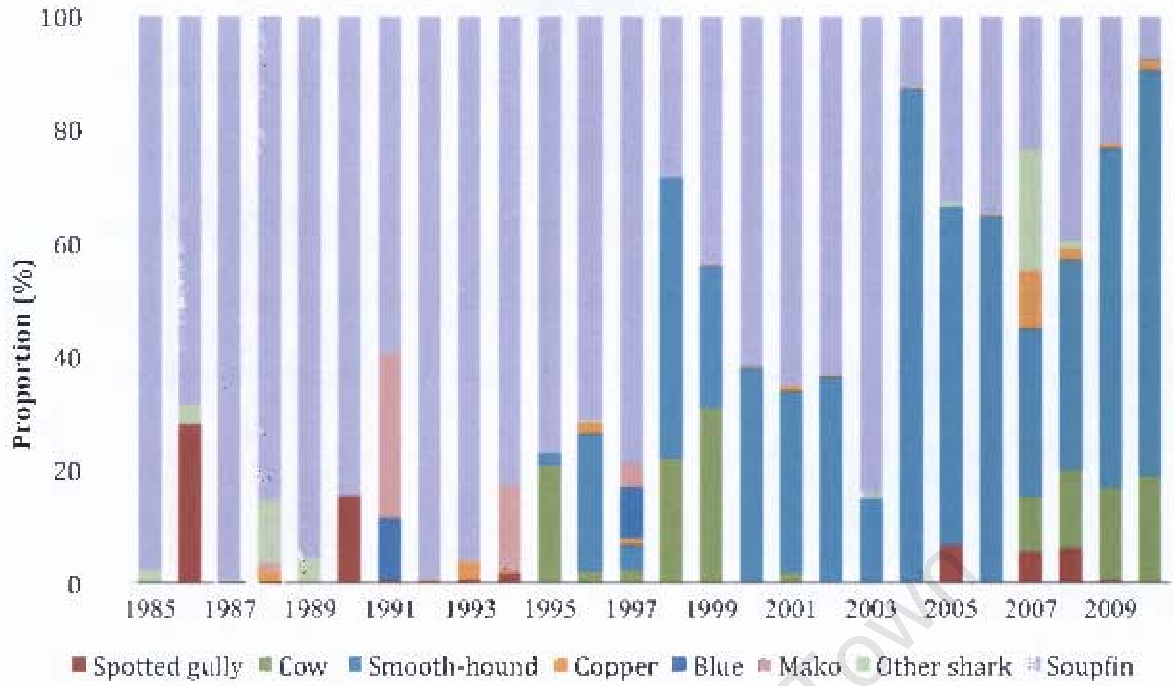

Figure 8. Species composition of the commercial linefish cartilaginous catch in False Bay between 1985 and 2010. The 'Other Shark' category includes all remaining chondrichthyan species caught in the linefishery not listed above.

Mean CPUE for the target shark complex showed a significant catch decline in one species and one genus, and an increase in abundance of three species (Appendix IV). *G. galeus*, showed a rapid decrease in mean CPUE. After alternating between five and 30 sharks per boat trip for almost ten years, the CPUE declined quickly and continued to oscillate between four and 7.5 sharks per boat, respectively. Mean CPUE for *Raja* spp. was low and erratic. An apparent decline in peak CPUE (0.003 to 0.0004 individuals per boat trip) occurred from 1985 to 2000 and was interrupted by a sharp increase to 0.006 CPUE in 2003, but subsequently crashed to zero until 2010 when catch increased to 0.0005 individuals.

In contrast, initial CPUE for *M. mustelus* was zero until 1995 when it began increasing, first to a mean of 1.6 CPUE in 1996 and ended with a peak mean of 17 sharks per boat trip in

2010. Mean CPUE of *C. brachyurus* fluctuated, showing two anomalous peaks in 1993 (1.1 sharks per boat trip) and 2004 (1.58 sharks per boat trip) above the background mean of 0.2 sharks per boat trip. Overall, however, a significant increase in *C. brachyurus* catch was found. *N. cepedianus* CPUE largely remained low between zero and 132 mean individuals per annum throughout the reporting period, but showed an abrupt increase in the final three years of the time series of 265, 879 and 1 039 sharks per annum similarly showing a significant overall trend of increase.

Analysis of beach seine catch returns

A total of 11 953 commercial beach seine hauls were reported in False Bay between 1974 and 2003. Beach seine effort peaked between 1983 and 1987, when an average of almost 800 hauls were made annually. Thereafter effort declined steadily to just 74 hauls in 2003. This decline largely reflects the removal of seine net permit holders from False Bay in an effort to reduce impact on surf zone teleosts. In contrast, beach seine surveys were limited to 586 hauls between 1991-1993, and were not performed again at any other time.

Similarity analysis of catch composition between commercial and survey seining catches indicated a significant difference ($R = 0.444$; $p<0.01$). This difference is likely due to the poor resolution of chondrichthyan identification and selectivity of reporting in the commercial catch data. Therefore, commercial and survey data sets could not be combined in a trend analysis. Because the survey data time series was so brief, long-term catch trends were not indicated by this data set.

Although the commerical catch time series began in 1974, reporting in the initial years was vastly incomplete and no chondrichthyans were recorded, probably as a result of selective sampling. Similarly, in 1981 and 1982, no chondrichthyans were reported, again suggestive of a reporting failure. These years were also removed from the data series. The proportion of chondrichthyans peaked prior to 1984 at 1.4% but remained between 0.01 and 0.4% for the remainder of the time series (Fig. 9).

Long-term trends in commercial CPUE of all chondrichthyans indicate a decline from a mean of one individual per haul per annum in 1979 to 0.032 individual in 2003 (Fig. 10).

$$CPUE = 63.6 - 0.032 \times YEAR,\ R^2 = 0.195,\ p = 0.031 \qquad \text{Eq. 3}$$

Correspondingly, species-specific trends in CPUE indicate declines for two chondrichthyans, *G. galeus* and *C. capensis*, however these species were the only chondrichthyans well represented in the commercial catch returns (Appendix V). In the case of *G. galeus* no catches were reported after 1984.

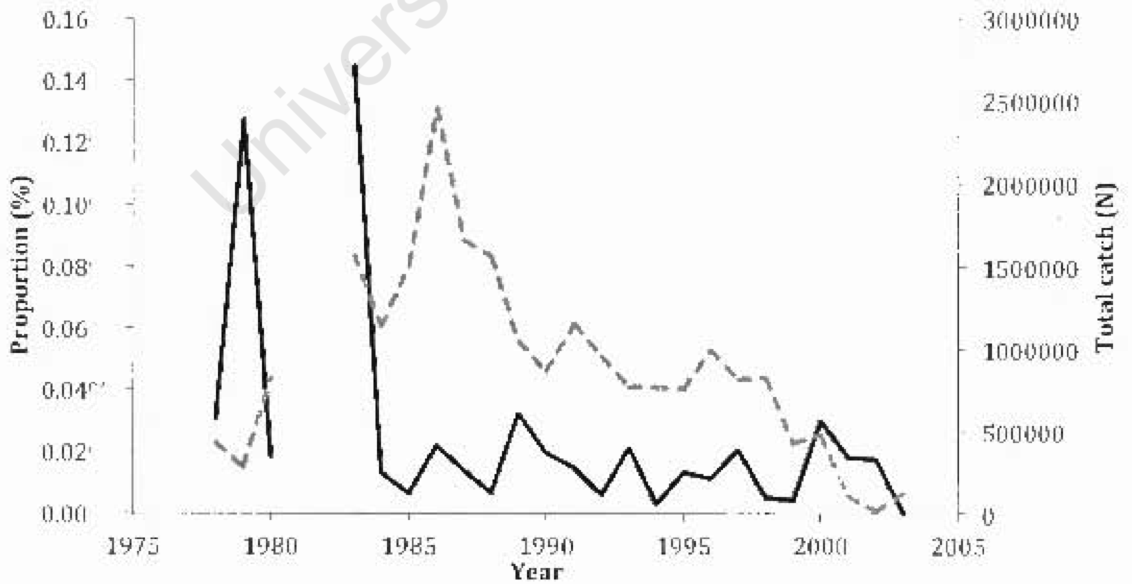

Figure 9. Annual proportion of chondrichthyans (solid line) caught in commercial beach seine nets and the total number (N) of all fish (dotted line) caught in False Bay beach seine nets from 1974-2003.

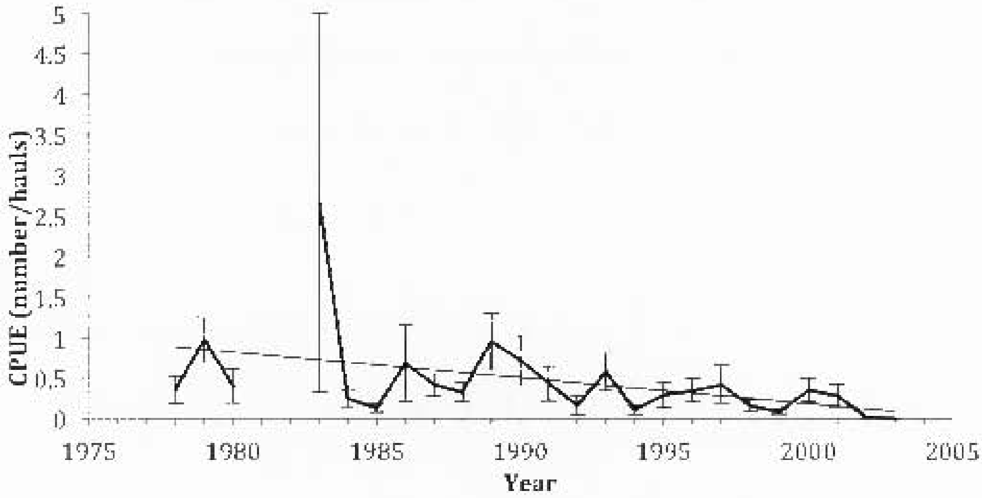

Figure 10. Mean annual catch per unit effort (CPUE) of all chondrichthyan species caught in False Bay commercial beach seine nets from 1975 to 2003. The straight line is the best-fit linear regression (CPUE = 63.6 – 0.032 × YEAR).

Analysis of recreational angling catch records

The annual catch of all fish and the proportion of chondrichthyans in the total catch of False Bay recreational anglers changed dramatically since records began in 1969 (Fig. 11). The proportion of chondrichthyans in the total catch increased from its lowest point of only 3% chondrichthyans in 1969, to the peak proportion of 98% chondrichthyans in 2011. This trend appears to represent an increased relative appearance of cartilaginous species in anglers' catch.

The multivariate analysis of the recreational data showed a strong relationship between catch composition and year. There is a clear trend between the first principle component and year, but the relationship is not linear (Fig. 12). The second principle component showed no obvious trend over time. The change reflects a shift from one time series to another and a likely shift in targeting and/or recording. As a result only the time period from 1989-2010 was considered comparable.

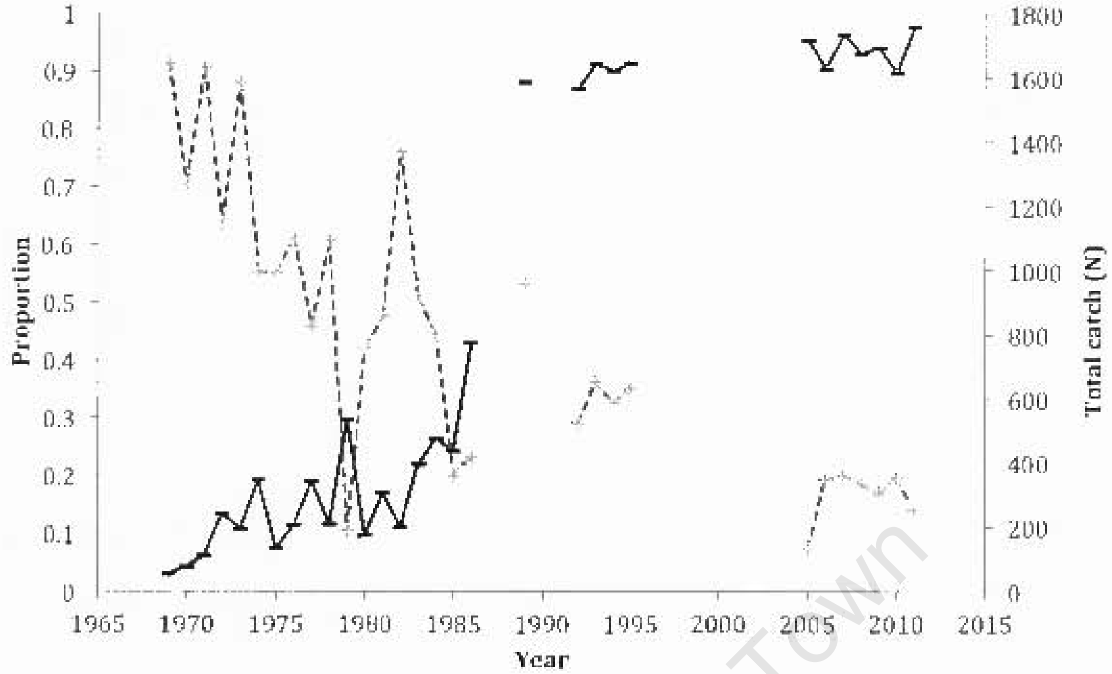

Figure 11. Annual proportion of chondrichthyans caught by recreational anglers beginning in 1969 until 1995 and from 2005 to 2011 (solid line). Total number (N) of all fish species caught annually by recreational anglers in the same time (dotted line).

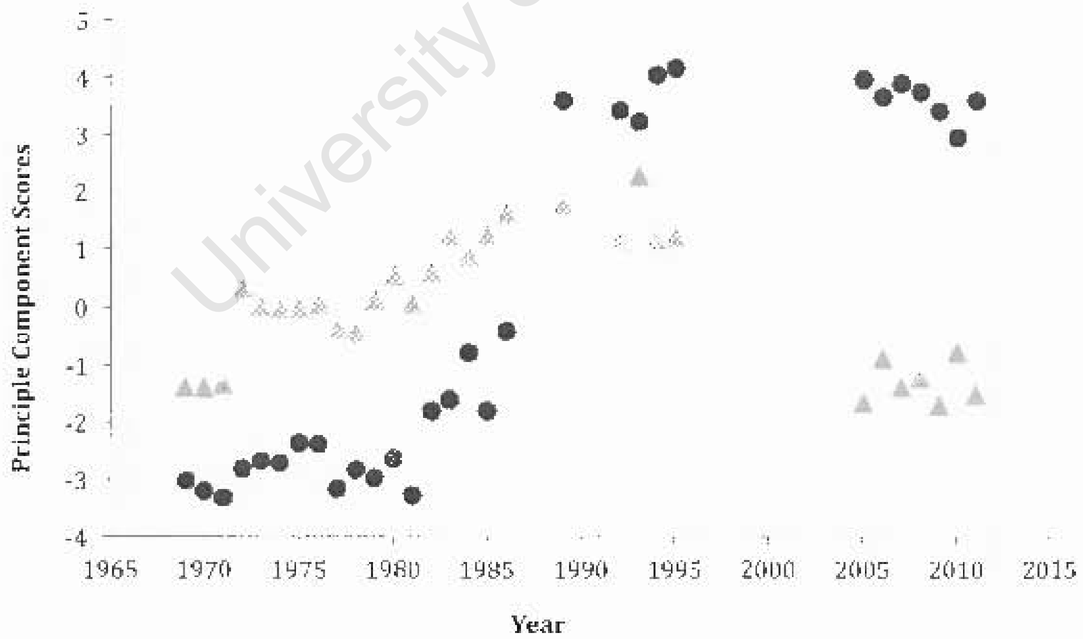

Figure 12. Principle components analysis (PCA) showing variation in species composition within the False Bay angling data from 1969 to 2011. PC1 (circles) explains most of the variation in community structure and PC2 (triangles) explains most of the remaining variation.

The catch proportions of six species in False Bay with some of the larger abundances in the angling time series (*C. capensis, C. brachyurus, G. galeus, N. cepedianus, Raja spp.* and *T. megalopterus*) are plotted separately in Appendix VI. *C. capensis* and *C. brachyurus* are two species that appear to have increased over the entire series. In the case of *C. capensis*, although the proportion seems to increase, the data are highly variable and interspersed with zero returns throughout, casting some doubt on the validity of the increase. This was confirmed by a rank correlation showing an insignificant catch trend. The relative contribution of *C. brachyurus* only became meaningful after 1982, thereafter it increased dramatically, but the last three years show a decline from the peak proportion of 37% in 2008. Although this trend was insignificant, these data may indicate a boom-and-bust type trajectory, however the data were too sparse to confirm such a pattern.

Rank correlation analysis revealed that the angling catch proportions for the remaining species all showed a significant decline. Catch for each species, excluding *Raja* spp., showed signs of a dome-shaped curve, suggesting a boom-and-bust trend in catch. *G. galeus* started the time series with a decline in catch proportion from 3.1% to 0.32% between 1972 and 1978, this was followed by a sharp increase peaking at 6.7% in 1984 and gradual decline to 1.3% in 1994. After a gap in reported catch, *G. galeus* made up only 0.6% of the total angling catch in 2006 and 1.4% in 2008 irrespective of the high proportion (90%) of chondrichthyans in the total catch at this time, indicating a drop in abundance. *N. cepedianus* does not appear in angling catches until 1983 with 1% of the total catch and increased to 7% in 1985. Catch proportion for *N. cepedianus* fell to 1% in 1992, but exploded to 25% of the total catch in 1993 before dropping as fast to 5% in 1994. Once angling records continued in 2005, catch proportion of *N. cepedianus* averaged 0.2% through to the end of the time series in 2011.

The substantial increase in angling catch proportion of chondrichthyans in 1985 is evident in both *Raja spp.* and *T. megalopterus* catches, peaking respectively in 1989 at 5 and 58% of the total catch. They similarly showed a general decrease through the remainder of the time series, contributing zero and 8% of the total catch in 2011, respectively. Overall *Raja spp.* and *T. megalopterus* showed a significant decrease in angling catch trends. The remaining three species and one genus that showed a significant catch trend were *M. mustelus, R. annulatus*, and *Dasyatis* spp. (including *D. chrysonota)*, all of which showed a significant increase in catch.

Analysis of demersal longline catch return

Between 1992 and 2011 (excluding 1993-1995 and 2004-2006) 225 commercial longline boat trips set 228 951 hooks in False Bay specifically targeting sharks. Effort (number of hooks) remained relatively low in the outset of the fishery, averaging under 3 500 hooks across 3.8 boat trips per annum. However, after 2007 effort increased considerably, averaging 48 350 hooks across 47.3 boat trips per annum (Fig 13). Total demersal longline catch was represented by only chondrichthyan species. The peak year in cartilaginous catch was 2008, delivering 3 180 individuals, but there after the number of chondrichthyans caught per annum declined to just under 900 individuals in 2011, suggesting an overall decrease in their abundance.

Correspondingly, longline mean CPUE for all chondrichthyans decreased over time, from 0.21 individuals per hook in 1992 to 0.02 individuals in 2011 (Fig. 14).

$$\text{CPUE} = 14.2 - 0.007 \times \text{YEAR}, R^2 = 0.24, p = 0.042 \qquad \text{Eq. 4}$$

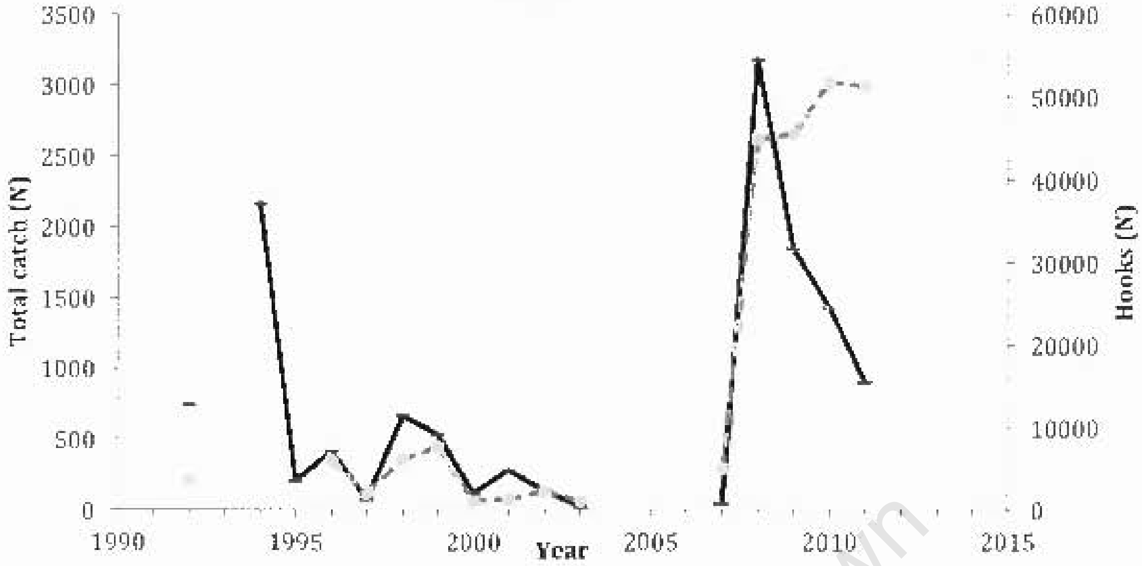

Figure 13. Commercial demersal longline total number of chondrichthyan catch (solid line) and annual number of hooks (dotted line) from False Bay between 1992 and 2011.

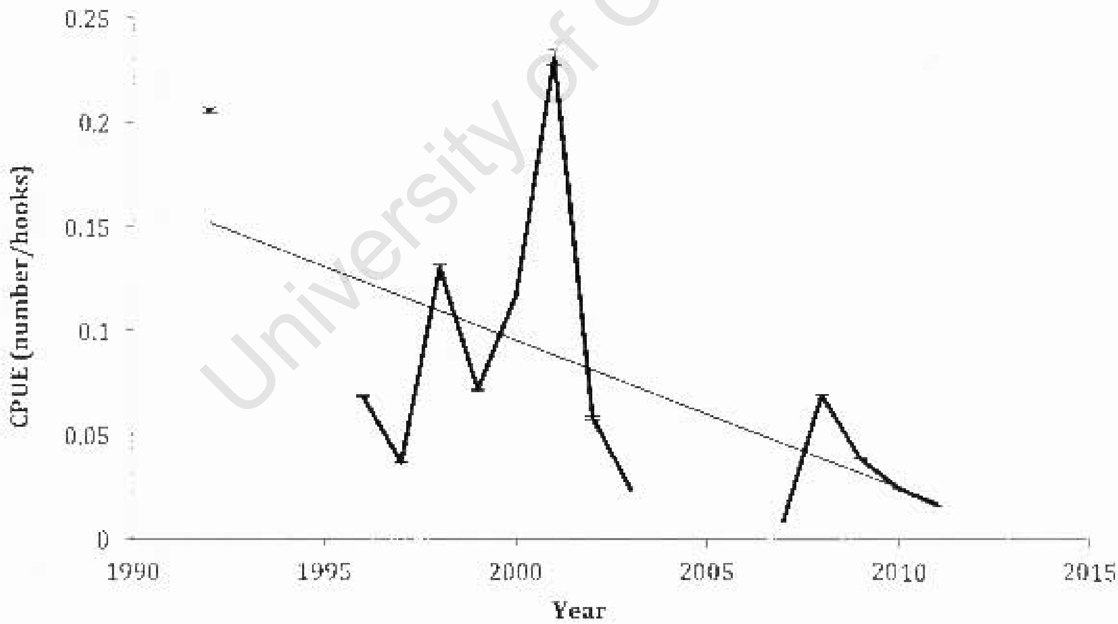

Figure 14. Demersal longline CPUE for all chondrichthyan species in False Bay, between 1992 and 2011. The straight line is the best-fit linear regression (CPUE = 14.2 – 0.007 × YEAR).

Individual mean CPUE trends for three target species in the False Bay demersal longline fishery (*G. galeus, M. mustelus,* and *N. cepedianus*) and one bycatch species (*Raja* spp.) appeared to decline in abundance (Appendix VII), however only one trend (*G. galeus*) was significant. Mean CPUE for *G. galeus* was 0.2 shark per hook in 1992 but dropped to an average 0.07 shark between 1997 and 2003. The final catch period in False Bay, between 2007 and 2011, showed additional catch decline for *G. galeus* CPUE to 0.01 mean shark.

In contrast, mean CPUE for *M. mustelus* appeared to increase. Although gaps in the recorded catch as well as zero catch returns throughout distort a trend in catch, the increase was significant. Similarly, CPUE for *N. cepedianus* and *Raja* spp. appear to be declining, dropping from a peak of 0.02 individuals per hook to 0.002, and from 0.02 to 0.007 individuals, respectively. The rank correlation analysis for *N. cepedianus* catch trend was not significant. The data for *Raja* spp. were compromised by a failure to report in the early part of the series and therefore showed a significant increase in catch. Two other species occasionally taken in demersal longline catches, *C. brachyurus* and *Prionace glauca* (blue shark), showed a significant increase in catch using rank correlation, however these species were, not recorded prior to 2007, which might indicate that these species were dumped in those years.

Analysis of historical trawl surveys

Between 144 trawl surveys, spread over 35 years in the early part of the 20th century, ten chondrichthyan species, five genera and one general 'shark' category were recorded in False Bay. Catch trend analysis of CPUE for each revealed three highly significant ($p<0.01$) results. These were three genera (*Dasyatis* spp., *Raja* spp. and *Torpedo* spp.) and they all showed a decline in catch over time (Appendix VIII).

2.3.2. Chondrichthyan vulnerability assessment

A majority of the 38 chondrichthyan species found in False Bay, excluding *Raja straeleni,* and *Torpedo fuscomaculata*, had life history parameters available to estimate population productivity. Twenty-eight species were considered to have very-low productivity, seven were low productivity species, and only one species had medium productivity (Appendix IX). Productivity for two genera, *Dasyatis* spp. and *Raja* spp., was also estimated because of the frequency of taxonomic lumping in these groups, and they were considered to have very-low and low productivity, respectively.

Individual catch trend analysis across all the major fishing methods in False Bay gave several trend estimates per species. These were either insignificant, increasing or decreasing (Table 2). Five species and one genus showed significant ($p<0.1$) declining trends (CPUE or proportion of catch) in at least one fishing method in False Bay. However, only one of these species and one genus, *G. galeus* and *Raja* spp., had a decline recorded by more than one method. *N. cepedianus*, showed a decline in one fishing method, but increased in another. From the remaining 33 species and one genus, three species and one genus showed significant population increase in only one fishing method, and *C. brachyurus* and *M. mustelus* increased in more than one method. The final 28 species showed no significant catch trends in any fishing method occurring in False Bay.

Abundance indices and productivity categories for each chondrichthyan species were compared to other risk criteria, including small population or endemicity, primary habitat and mortality threats in False Bay (Appendix IX). Sixteen species had either a small population or were endemic to Southern or South Africa and thus were range restricted. Those species also experiencing catch declines and/or had low or very-low productivity were at least classified as a *conservation concern*. The remaining 22 species were either cosmopolitan species or had large connected ranges extending further than Southern Africa (nominally from Namibia to Mozambique) and therefore were not threatened by range restriction.

Table 2. Abundance indices for chondrichthyan species showing significant catch trends in False Bay fisheries catch records: commercial linefish (CL), commercial beach seine (CBS), recreational angling (RA), and demersal longline (DL).
Significance: + or - = 0.1>p>0.01, + + or - - = 0.01>p>0.001, + + + or - - - = p<0.001

Method n Years	**CL** 26 1985 - 2010	**CBS** 24 1978- 2003	**RA** 12 1989-2011	**DL** 14 1992-2011	**Common Trend**
Callorhinchus capensis		-			None
Carcharhinus brachyurus	+			+	**Increasing**
Dasyatis spp.			+		None
Dasyatis chrysonota			+		None
Galeorhinus galeus	- -	-	- -	- -	**Decreasing**
Mustelus mustelus	+ + +		+	+	**Increasing**
Notorynchus cepedianus	+		- -		None
Prionace glauca				+	None
Raja spp.	-		-		**Decreasing**
Rostroraja alba			-		None
Rhinobatos annulatus			+		None
Triakis megalopterus			- -		**Decreasing**

Cartilaginous species in False Bay occur within several habitats; these largely include demersal, reef, soft sediment, pelagic and surf zone habitats. Different levels of threat can be associated with different habitats, as a result species within them are more or less vulnerable to exploitation. The majority of False Bay chondrichthyans, 13 species (34%), primarily occur on or near the bottom and may be associated with reef, sandy or unconsolidated sediment habitats. Nine species (24%) are predominantly found in rocky reef habitats, whereas eight species (21%) prefer soft sediment areas. Six species (16%) are considered pelagic and therefore regularly found within the water column, and the two remaining species (5%) are often found in and around the surf zone.

After considering all of the factors above, the susceptibility or threat of 38 chondrichthyan species and two genera to damaging exploitation in False Bay was evaluated (Table 3). Populations of two species, representing 5% of chondrichthyans, were considered *stable* in False Bay. One chimaera species and one genus, 5% of chondrichthyans, were *vulnerable* to exploitation. Another 5%, representing two species, were *threatened* by exploitation in False Bay and 34%, 13 species, were of *conservation concern*. Finally the majority, 20 species and one genus, had *unknown* status and may require further investigation. At least ten species were rarely caught in any fishing method, and therefore the lack of catch trend was likely an indication of low power.

Table 3. False Bay, South Africa, chondrichthyan conservation assessment. KZN (KwaZulu-Natal), SA (South Africa).

Species	Status in False Bay	Reason for False Bay classification
Alopias vulpinus	Unknown	
Callorhinchus capensis	**Vulnerable**	Signs of declining CPUE; low productivity; southern African endemic; target in commercial fisheries
Carcharhinus brachyurus	**Stable**	Significant increasing CPUE in two fisheries; discrete regional population from Namibia to KZN
Carcharhinus brevipinna	Unknown	
Carcharhinus limbatus	Unknown	
Carcharias taurus	Unknown	
Carcharodon carcharias	Unknown	
Dasyatis spp.	Unknown	
Dasyatis brevicaudata	Unknown	
Dasyatis chrysonota	**Conservation concern**	Signs of declining catch; very low productivity; endemic from Angola to southwestern Cape, SA; bycatch species
Dasyatis thetidis	Unknown	
Etmopterus granulosus	Unknown	
Galeorhinus galeus	**Threatened**	Significant CPUE decrease in multiple fisheries; very-low productivity; commercial fisheries target
Gymnura natalensis	**Conservation concern**	Very-low productivity; endemic from Namibia to Mozambique; bycatch in multiple fisheries
Halaelurus natalensis	**Conservation concern**	Very-low productivity; south coast, SA endemic; bycatch in multiple fisheries
Haploblepharus edwardsii	**Conservation concern**	Very-low productivity; south coast, SA endemic; bycatch in multiple fisheries
Haploblepharus pictus	**Conservation concern**	Very-low productivity, south coast, SA endemic; bycatch in multiple fisheries
Isurus oxyrinchus	Unknown	
Mustelus mustelus	**Stable**	Significant CPUE increase in multiple fisheries; common; commercial fisheries target
Myliobatis aquila	Unknown	

Narke capensis	**Conservation concern**	Low productivity; endemic from Namibia to KZN; bycatch in multiple fisheries
Notorynchus cepedianus	**Conservation concern**	Catch decline in fishery that targets this species; very-low productivity; southern Africa subpopulation
Pliotrema warreni	**Conservation concern**	Very-low productivity; endemic from south coast, SA to southern Mozambique
Poroderma africanum	**Conservation concern**	Very-low productivity; south coast, SA endemic; bycatch in multiple fisheries
Poroderma pantherinum	**Conservation concern**	Very-low productivity; south coast, SA endemic; bycatch in multiple fisheries
Prionace glauca	Unknown	
Pteromylaeus bovinus	Unknown	
Raja spp.	**Vulnerable**	Decreasing CPUE; low and unknown productivity of some *Raja* species; bycatch in multiple fisheries
Raja clavata	Unknown	
Raja miraletus	Unknown	
Raja straeleni	Unknown	
Rostroraja alba	Unknown	
Rhinobatos annulatus	**Conservation concern**	Very-low productivity; endemic from southern Namibia to KZN; abundant, but large catch in some fisheries
Scyliorhinus capensis	**Conservation concern**	Very-low productivity; endemic from southern Namibia to KZN; bycatch in multiple fisheries
Sphyrna zygaena	Unknown	
Squalus acanthias	**Conservation concern**	Very-low productivity; distinct regional population from Namibia to KZN; abundant, but large catch
Squalus megalops	Unknown	
Torpedo fuscomaculata	Unknown	
Torpedo marmorata	Unknown	
Triakis megalopterus	**Threatened**	Significant decreasing CPUE; very-low productivity; endemic from Angola to KZN; large bycatch

2.4. Discussion

2.4.1. Data availability

Fishing activity in False Bay represents only a small portion of the total wild capture fisheries around South Africa, yet almost every kind of fishing is represented. Most fisheries either target or incidentally catch chondrichthyans along with their primary catch (WWF 2011). Two exceptions are purse-seining and rock-lobster trapping, which, although present in False Bay, do not report any chondrichthyan catches.

The data presented hold information on fish abundance in the majority of the habitats in False Bay—angling and beach seine cover the majority of shoreline and adjacent surf zone areas, whereas linefishing covered pelagic water, reef, kelp bed and soft-sediment habitat. Although the combination of these three methods present themselves as a strong source of monitoring data for chondrichthyans they probably underrepresent the deep (> 40 m), soft-sediment habitat that dominates False Bay. Soft-sediment habitats are effectively covered, however, by trawl and demersal longline, though trawling has been banned since 1928.

An important aim of this work was to identify the most effective data sources for monitoring the status of the full spectrum of chondrichthyan species. Not only should the method, or combination of methods, be sufficiently broad to include all species by being non-selective and applied in a variety of habitats, but it should also cover the majority of the Bay under the majority of environmental conditions. Three methods are immediately discounted, namely SCUBA, spearfishing and poisoning. Whereas SCUBA is a broad spectrum technique, and non-destructive, it covers only very specific parts of the Bay, and is severely dependent on environmental conditions. Poisoning, an important component of ichthyological surveys, and spearfishing are simply too selective to represent chondrichthyans. None of these methods yielded species absent from the other data sources.

Another important consideration is the length of the time series available. The commercial linefish data are the most comprehensive in terms of temporal extent, spanning 25 years, relatively high taxonomic resolution and the inclusion of essentially all commercial catch records. As a result this data set provides the most information on individual chondrichthyan catch trends. Second, recreational angling had comparatively higher taxonomic resolution and covered 30 years, spanning four decades, but did not represent a complete data set with some angling club records and competition data absent. Regardless, this data set produced multiple significant catch trends showing the importance of these records and the need to continue collecting such data.

Beach seine survey data, while having precise species identification, were only three years long and could therefore only provide detailed information on species composition. Commercial beach seine, on the other hand, spanned almost 30 years however operators periodically lumped chondrichthyans into general categories obscuring some long-term species catch trends. The poor taxonomic resolution can be attributed to the fisheries primary target—edible, marketable fish. Demersal longline data, though only recently increasing in effort, represents an important data set because it not only targets chondrichthyans, and would therefore provide important species catch trends, but longlining also samples less commonly represented deep, soft-sediment habitats. Finally, trawling not only had a moderate temporal extent, as well as being the oldest data, it also had fine resolution species identification. However, because of the ban on trawling no trawl surveys have been conducted in False Bay since 1947, though chondrichthyans were not recorded in scientific trawl surveys after 1932, demonstrating a lack of interest in this group and as a result there are no current data for direct comparison.

Commercial linefish and recreational angling contained the most informative data and were most comparable in species composition when considering all fish species. But when considering only chondrichthyan composition commercial linefish was more similar to demersal longline and recreational angling to beach seine survey, which is largely to do with the location and habitats fished. Each of these main data sets contained varying levels of information with emphasis on different species, and as a result the combination of methods enhances the power of monitoring catch trends.

2.4.2. Diversity and distribution

The fishing methods with the highest chondrichthyan diversity, recreational angling and commercial linefish, combine to cover 76% of chondrichthyan species in False Bay. Beach seine survey recorded another 16%. The remaining 8% were recorded only in trawls. Collectively these three methods recorded 38 chondrichthyan species in False Bay.

The total chondrichthyan diversity found within False Bay (23 sharks, 14 skates/rays and one chimaera) is comparable to other areas around the world, many of which encompass significantly larger areas and deeper depths. For example, the entire state of California, which similarly includes warm-water and cold-water species, has 43 sharks, 22 rays and three chimaera species, none of which are endemic to the area (Ebert 2003). Specifically 19 sharks, 10 batoids (skates and rays) and one chimaera occur in Monterey Bay, California (Kukowski 1972). The 1 200 km long Gulf of California, in Mexico, has recorded a total of 87 chondrichthyan species (Hastings et al. 2010). The Mediterranean Sea, which covers an area of approximately 2.5 million square km and has an average depth of 1 500 m, significantly larger and deeper than False Bay, has 45 species of shark, 30 batoids, and one chimaera, of which only four species are endemic (Cavanagh & Gibson 2007).

Additionally, trawls from 0 to 300 m in the central Aegean Sea of the Eastern Mediterranean recorded 13 sharks, 16 batoids and one chimaera (Damalas & Vassilopoulou 2011). Shark Bay, Western Australia, a large (about 13 000 square km) semi-enclosed bay known for its diversity, has a total of 28 chondrichthyan species recorded within the Eastern Gulf of the bay (Vaudo & Heithaus 2009). In the southwestern Atlantic along the central-eastern coast of South America, in similar latitudes to South Africa, only 13 species of chondrichthyan were found (Menni et al. 2010). Lastly, longline surveys in and around the mouth of the Chesapeake Bay of the U.S. Mid-Atlantic coast recorded 20 shark species between 1974 and 1991 (Musick et al. 1993). Although some of these areas report a greater diversity of chondrichthyan species than False Bay, in all cases this diversity is spread across a much larger area and in most cases included depth beyond those in False Bay, as a result these locations include a wider range of habitats and are therefore expected to contain more species. Given the relatively smaller size and shallow depth of False Bay the diversity is comparatively high.

The high diversity of fauna found in False Bay can largely be attributed to the unique contrast of the two major oceanic currents on the East and West coasts of South Africa (Branch et al. 2002) that converge on the South Coast between Cape Agulhas and Cape Point (Griffiths et al. 2010). The Agulhas Current runs south along the Indian Ocean coast to the east, sweeping warm water from the subtropics across the Agulhas Bank. Whereas the Benguela Current, driven by cold-water upwelling, runs northward along the Atlantic coast to the west (Griffiths et al. 2010). Upwelling results in deep, cold nutrient-rich waters reaching the surface where it fuels highly productive food-chains. Though the productivity is higher on the West Coast, it supports fewer species then the East Coast, which is especially diverse because of the high numbers of tropical Indo-Pacific species (Branch et al. 2002). Despite this, a majority, 37%, of False Bay chondrichthyans were of Atlantic origin whereas 18% of species were predominantly from the Indo-Pacific.

Of the newly recorded species to False Bay there is a possibility of misidentification. For example, *C. brevipinna* is often confused with *C. limbatus* (Burgess 2009), a shark species known to occur as far south as False Bay in summer, and vice versa. However, *C. brevipinna* was recorded on separate occasions reducing the likelihood of a mistake. In addition, *E. granulosus* may have been misidentified, and may in fact be one of the other *Etmopterus* spp. that occurs off the southern coast. Taxonomic confusion within this group has led to some revision and it is possible *E. granulosus* was in fact *Etmopterus baxteri,* also referred to as the southern lantern shark (Paul 2003). Nevertheless the six individuals were vastly out of the published range for any of the lantern shark species.

Similarly, it is possible that *Torpedo fuscomaculata* was confused with another *Torpedo* species, taxonomic resolution of this group is poor and this species has never been studied (Pheeha 2004). Nonetheless, the torpedo was caught in a beach seine survey and it is unlikely the scientists, who were experienced at species identification, would have misidentified it. *Raja straeleni* was first recorded in a commercial beach seine net, but ten years later also identified in survey-seine nets and again is unlikely to have been misidentified by scientists. It is possible, however, that this species has occurred in False Bay for longer and was either confused with *R. clavata* (Smale 2009a) or repeatedly lumped with other *Raja* species, and therefore overlooked. *Dasyatis thetidis* has only been identified twice in recreational angling records and it is possible it was confused with *Dasyatis brevicaudata* (short-tail stingray), though it is more likely that this species was occasionally found in False Bay but has been previously misidentified or lumped with other *Dasyatis* species. Finally, *Gymnura natalensis* was unlikely to have been misidentified because it is now commonly caught in False Bay and is said to occur from Namibia to Mozambique (Wintner 2006), and therefore represents a case in which the full species range was previously unknown.

Misidentification of regularly caught species also occurs. *T. megalopterus* is often confused with *M. mustelus* in catch records by anglers and linefishermen (Compagno et al. 2005a) and *Rhinobatos blochii* (bluntnose guitarfish) misidentified with *R. annulatus* (Burgess & Marshall 2006). This could explain why *R. blochii,* a species said to occur to Cape Point, is not recorded in any catches.

2.4.3. False Bay fisheries

The 20th century has seen the rise and fall of multiple fisheries in False Bay, all of which have had an impact on chondrichthyan populations. Commercial exploitation within the Bay has been on-going since the 17th century (Penney 1991), beginning with linefish and beach seine fisheries, both of which have seen a drop in effort in the last few decades. While the proportion of chondrichthyans in the beach seine catch has similarly decreased, the cartilaginous catch in the commercial linefishery has actually increased in recent years, further magnifying the pressure of exploitation on these vulnerable species in almost all habitats. At the turn of the 20th century demersal trawling was introduced to False Bay, and for 30 years would have removed substantial numbers of chondrichthyans (Pauly et al. 2002; Attwood et al. 2011), many of which would have been discarded. Trawling is one of the least selective methods of fishing and is known to have profound effects on the ecosystem and community assemblages (Atkinson et al. 2011). Trends in the historical trawl surveys from False Bay revealed that after 30 years significant ($p<0.01$) declines in catches of *Tropedo*, *Dasyatis,* and *Raja* species had occurred. Most of these are low to very-low productivity species, and as expected, would be the first to respond negatively to such exploitation. Trawling was later banned to protect valuable inshore fish stocks and to reduce competition with linefishers, effectively creating deep-water sanctuaries protecting these habitats and associated species from damage and exploitation.

Recreational angling, on the other hand, developed more recently and has grown exponentially, as has the proportion of cartilaginous species in the total catch (Bennett 1991). Like the beach seine fishery the majority of the fishing effort is concentrated in the surf zone impacting a different community of species from linefishing. Although directed shark fishing started in the mid-1900s with rise in demand for vitamin A, it was only in the 1990s that a formalised shark longline industry was developed (Da Silva & Burgener 2007). Shark longlining makes up the second largest (to trawl) exploitation of sharks in South African waters (Sauer et al. 2003), but has only increased recently in False Bay. The demersal shark fishery primarily concentrates on five shark species: *M. mustelus, G. galeus, C. brachyurus*, *Carcharhinus obscurus* (dusky shark) and *Mustelus palumbes* (whitespotted smooth-hound), but also takes *T. megalopterus, C. limbatus, S. zygaena* and *N. cepedianus* (Da Silva & Burgener 2007). Only a small proportion of the chondrichthyan species found in False Bay, however, are directly targeted for commercial exploitation. The majority are caught as bycatch in the many commercial and recreational fisheries found in and around the Bay and are often discarded, unrecorded in commercial catch.

Though results from the commercial linefish analysis confirm that this fishery, in general, does not primarily target chondrichthyans, large catches of fish species corresponds to low catches of chondrichthyans in times of decreased abundance. However, if the line-fisherman's primary catch is low chondrichthyans are relied upon as a replacement. Commercial beach seine returns represent the smallest proportion of the overall cartilaginous catch and the proportion of chondrichthyans in the total commercial seine catch has decreased over time. This trend may be the result of an overall chondrichthyan decline, but is more likely explained by reduced fishing effort through the issuing of limited commercial permits.

Conversely, recreational angling in False Bay has unmistakably shifted its focus toward cartilaginous species, and currently angling represents the largest proportion of total chondrichthyan catch and thus the largest potential threat to chondrichthyans. This shift may be due, in part, to the increased popularity for anglers to target shark beginning in 1980, specifically targeting larger species in angling competitions to increase anglers overall score (Taylor 1984; Bennett 1991). Though many anglers now practise catch-and-release, for most species it is unknown to what extent these species survive, and survival largely depends on the way in which the individual is handled and for how long (Lack & Sant 2009). On the other hand, demersal longlining in False Bay is a comparatively recent fishery. Though their catch almost exclusively comprises of chondrichthyans, in False Bay, this fishery took relatively few prior to 2007. However, longline catch data were showing an increase in effort, and a decrease in cartilaginous catch, further providing evidence for chondrichthyan population declines.

2.4.4. Species-specific trends in False Bay

Galeorhinus galeus

Owing to the very-low productivity of *G. galeus*, age at maturity of up to 20 years for some females and maximum recorded age of 30+ years (Walker et al. 2006), their susceptibility to exploitation is high and this is supported by trends in catch abundance. *G. galeus* is the most commonly caught chondrichthyan in False Bay, as such when chondrichthyans were taken in the commercial linefishery *G. galeus* made up the majority of the cartilaginous catch. However, the annual proportion gradually declined over time. This trend corresponds with a highly significant ($p<0.01$) decrease in abundance of *G. galeus* found from 1985 to 2010 in commercial linefish catch. A similar significant trend in reduced catch abundance was found for commercial beach seine, recreational angling and demersal longline, together these represent a strong signal of a population threatened by overexploitation.

This declining trend has been documented in other *G. galeus* populations in South Africa and around the world (Walker et al. 2006). In South Africa, *G. galeus* has been targeted to varying degrees since the 1930s, and a catch rate decline in the handline fishery along the South African coast has been documented (McCord 2005). Interestingly, despite this decline, a report on South Africa's fisheries (WWF 2011) considers this species to be optimally exploited, as of 2007, in the commercial linefishery. However, declines have also been documented in the California fishery for *G. galeus* that collapsed after just eight years of intense exploitation (Ripley 1946), in addition to other fishery declines in Argentina (Chiaramonte 1998) and Australia (Punt et al. 2000).

Mustelus mustelus

Although *M. mustelus* is a relatively smaller shark it also has very-low resilience, maturing in 10+ years with a maximum age of around 25 years (Serena et al. 2009). *M. mustelus* is the next most common chondrichthyan species caught in False Bay, and similarly shows an overall significant catch trend, however, it is an increasing trend. A shift in targeting of *G. galeus* in the commercial linefishery toward *M. mustelus* has resulted in an on-going increased catch since its first appearance in 1995. Weakly significant ($p<0.1$) increasing catch trends have also been recorded in recreational angling and demersal longline. Conversely, *M. mustelus* was considered over-exploited in the commercial linefishery in 2007 (WWF 2011).

Though *M. mustelus* catch has increased in False Bay, and is generally considered a more fecund species (Smale & Compagno 1997; Walker 1998), declines in its landings have been recorded in South Africa (Da Silva 2007), the Mediterranean (Munoz-Chapuli et al. 1994; Fergusson 1996), Peru (Bonfil et al. 2005) and Mauritania (Gascuel et al. 2007). However, generally little species-specific fisheries catch data were available because landings data often refer to all *Mustelus* species combined (Smale & Compagno 1997; Serena et al. 2009). A possible explanation for the increase in *M. mustelus* catch in False Bay—a smaller chondrichthyan species—*M. mustelus,* is regularly prey for larger shark species and decline in these large species could result in the increased abundance of their prey (Myers et al. 2007).

Rhinobatos annulatus

Although *R. annulatus* is the third most commonly caught chondrichthyan an increase in catch was weakly significant ($p<0.1$) only in recreational angling, and therefore no overall abundance trend could be determined. This species is considered to have higher productivity than other chondrichthyans because it matures at around three years and has a maximum age of approximately seven years (Burgess et al. 2006). However, because it is a Southern African endemic, and naturally has a small range, *R. annulatus* is vulnerable to overexploitation.

Callorhinchus capensis

Another species with relatively high productivity, *C. capensis*, reaches maturity in three to four years and has a maximum age of around ten years (Pheeha & Dagit 2006). A targeted commercial fishery for *C. capensis* in the False Bay beach seine fishery has been on going since 1980 (Sauer et al. 2003), however, catch records from this fishery show evidence of decreasing abundance. Like *R. annulatus, C. capensis* is a Southern African endemic and although it is considered common throughout most of its range it is also taken in the demersal trawl fishery, as bycatch, outside False Bay thus intensifying exploitation pressure.

Notorynchus cepedianus

A larger shark with very-low productivity, reaches maturity in an average of 15 years and has 30+ years longevity (Compagno 2005a), *N. cepedianus* is targeted in multiple fisheries in False Bay and shows conflicting catch trends. This species is vulnerable to overexploitation because the population is limited to inshore temperate waters in subpopulations (Compagno et al. 2005a). A weakly significant ($p<0.1$) increasing trend was found in the False Bay commercial linefishery, and a stronger declining trend ($p<0.01$) in recreational angling, however this might reflect a shift in targeting.

Increased exploitation has led to declines in a few other populations around the world, for example, the fishery in Namibia collapsed after just nine months (Ndjaba 1998), and the stock in San Francisco Bay have been depleted since the 1980s (Compagno 2005a). However, because of a lack of fisheries data elsewhere it is impossible to determine whether this pattern of depletion definitely occurs throughout its range (Compagno 2005a).

Raja spp.

Species of the genus *Raja,* including *R. clavata, R. miraletus, R. staeleni* and *Rostroraja alba* (formally *Raja alba*), are bycatch in most fisheries and therefore lumped together (Stevens et al. 2000) preventing species-specific trends. Life history parameters for this genus vary; for example, *R. clavata* has low productivity with five+ years to maturity, longevity of 10+ years and produces between 50 and 150 eggs annually (Ellis 2005), whereas *R. miraletus* is more fecund, maturing in two to three years, lives for a total of ten years and lay eggs continuously throughout the year (Smale et al. 2009). Parameters for the other two species are unknown (Dulvy et al. 2006; Smale 2009a).

In False Bay, *Raja* spp. catch is decreasing significantly ($p<0.1$) in both the commercial linefishery and in recreational angling, and specifically *R. alba* is declining in the recreational catch. Additionally, catch trends from False Bay historical trawl data showed a highly significant ($p<0.01$) decline in catch from 1897 to 1932. In support of these trends are declining catches in other fisheries documented in other parts of the world. In the Mediterranean most large *Raja* species are less abundant than in the past, especially *R. alba* (Munoz-Chapuli et al. 1994), and *R. clavata* has decreased across its range in the North Sea (Walker et al. 2005). However, increased catch of *R. miraletus* in the Mediterranean is believed to be the result of release from predation by larger sharks (Jukic-Peladic et al. 2001).

Triakis megalopterus

Another Southern African endemic, *T. megalopterus* is uncommon and highly vulnerable to exploitation in unregulated shark fisheries (Compagno 2009). This vulnerability is the result of very-low productivity because of *T. megalopterus'* late maturity, particularly long gestation period and longevity (Smale & Goosen 1999; Booth et al. 2011). Tag returns suggest very high longevity (ORI 2009) and site-fidelity (C. Attwood pers. comm.). *T. megalopterus* is targeted by shore-anglers—an illicit market has encouraged targeting by small but active part of this fraternity in False Bay (C. Attwood pers. comm.)—and it is taken as a minor bycatch in the demersal longline fishery (Compagno 2005b), which suggests that this species is currently under threat.

In False Bay, *T. megalopterus* was the most commonly caught chondrichthyan in the linefishery and showed a dramatic decline after a peak catch in 1990, and remained low through the end of the time series. This trend again strongly points to overexploitation. Additionally, a highly significant ($p<0.01$) declining trend in recreational angling was shown in this study. Though there are no other separate statistics available from commercial catches of *T. megalopterus* in Southern Africa to compare trends with (Compagno 2005b), either because of misidentification or taxonomic lumping of this species, research demonstrates this species can sustain only very limited fishing pressure (Booth et al. 2011).

Myliobatis aquila

Although *M. aquila* is commonly caught as bycatch in most False Bay fisheries no significant trend was detected in this study. Life history parameters for this species appear to vary regionally, the maximum size of *M. aquila* is significantly smaller off Southern Africa and females produce an average of five pups annually, however little else is known about their productivity (Holtzhausen et al. 2009). The population of *M. aquila* exploited off of France in the northwestern Mediterranean Sea has shown a long-term trend of decline, ultimately resulting in local extinction (Aldebert 1997). However, catch data from KwaZulu-Natal's shark nets showed no trend from 1981 to 2001 (Young 2001). No other data are currently available on catch trends elsewhere (Holtzhausen et al. 2009).

Carcharhinus brachyurus

Very-low productivity, the result of reaching maturity in around 15 years and a lifespan of approximately 30 years, in addition to being targeted or taken as bycatch in multiple fisheries makes *C. brachyurus* vulnerable to overexploitation (Duffy & Gordon 2003). Further exacerbating the vulnerability of *C. brachyurus*, it is believed that regional populations, such as the Southern African population, are discrete and movement of individuals between them is infrequent or absent, more still this species does not appear to be naturally abundant anywhere (Duffy & Gordon 2003). Despite this an overall increasing trend, due to weakly significant increases in catch trends in both commercial linefish and demersal longline, for *C. brachyurus* was found in False Bay. However, trends in the New Zealand fishery and fisheries in East Asia have shown decline, and because landings of *C. brachyurus* are grouped with other *Carcharhinus* species any other population declines are likely to go unnoticed (Duffy & Gordon 2003).

Dasyatis chrysonota

A more fecund species, *D. chrysonota* matures between five and seven years of age and lives for nine and 14 years for males and females, respectively. Females give birth to a litter of one to five pups annually (Cowley 1990). However, *D. chrysonota* is a Southern Africa endemic with a depth-restricted range, and although it is not targeted, *D. chrysonota* is regularly caught by shore anglers, in beach seine nets and taken as bycatch in trawlers outside False Bay (Smale 2009b), further increasing its vulnerability to exploitation.

Although no catch trends have been documented for *D. chrysonota* in other parts of South Africa, catch in False Bay recreational angling records show a weakly significant increase. Furthermore, because *D. chrysonota* makes up the bulk of the *Dasyatis* spp. catch a weakly significant increasing trend was also found for the genus as a whole.

Squalus spp.

In South Africa, like *Raja* species, *Squalus* species (*S. acanthias* and *S. megalops*) are often lumped together in catch records and as a result individual species catch trends are not possible. Additionally, *S. acanthias* was only recorded in historical trawl records, but this may only be due to later misidentification of *S. megalops*. Although naturally abundant, *S. acanthias* is one of the more vulnerable species of shark to over-exploitation by fisheries because of its late maturity, low reproductive capacity, longevity, long generation time (25 to 40 years) and hence a very low intrinsic rate of population increase (Fordham et al. 2006). Similarly. *S. megalops* has very-low productivity taking up to 20 years to reach maturity and producing only a few young after a two year gestation period (Cavanagh & Lisney 2003).

Although no significant catch trend was found in False Bay, generally, locally high biomass initially supports large catches, however most large-scale *Squalus* fisheries have depleted populations and collapsed (OWC 1996). Though *S. acanthias* has a subpopulation in Southern Africa (Fordham et al. 2006), declines have been documented in several other fisheries in the northeast Atlantic (Pawson & Vince 1998), Mediterranean (Aldebert 1997); Black Sea (Prodanov et al. 1997); northwest Atlantic, eastern and western North Pacific (Ketchen 1975;

Fordham et al. 2006). *S. megalops,* on the other hand, is common to abundant in temperate and tropical seas and is of considerable interest to trawl and line fisheries, however population trends for this species are unknown (Cavanagh & Lisney 2003).

Rarely caught species

The remaining 23 species are only occasionally recorded in catch records from the main False Bay fisheries and are either rare species and/or represent bycatch and are therefore often discarded unreported. Though these species showed no catch trends this does not mean they are not being impacted by exploitation, as the problem may simply be a lack of statistical power in the data. The protection of these species should not be ignored until more data are available. Using information on other aspects, such as range and life history, something can be inferred of their vulnerability to continued catch, and if nothing else some species can be prioritized for research, monitoring or inclusion in protected areas.

2.4.5. Chondrichthyan assessment

Assessment techniques

The problems with monitoring cartilaginous fish populations using fisheries catch data mostly revolve around a lack of species-specific information. The assessment and monitoring of chondrichthyan fishes depends primarily on reliable fisheries data, specifically landed catch, bycatch, discarded catch and discard mortality, and secondly on the basic biological knowledge for each species (Camhi et al. 1998). Not only is there a widespread lack of reporting, inaccurate record keeping and in some cases wilful underestimations limits the quality of fisheries data (Cavanagh 2005), but the biology and taxonomy of cartilaginous fishes is among the most poorly know of all marine vertebrate groups, and most have not been reliably aged (Cailliet et al. 2005). Currently the lack of high quality data from both sources restricts efforts to manage or conserve chondrichthyan species (Musick 2005).

To effectively conserve and manage cartilaginous fishes stock assessments, or assessments of extinction risk, are vital. There are several methods available to perform stock assessments of chondrichthyans (GFCM 2010). Dulvy et al. (2004) summarize three general methods: (i) correlative approaches based on knowledge of life histories and ecology; (ii) time-series approaches that examine changes in abundance; and (iii) demographic approaches based on age- or stage-based schedules of vital rates and fisheries reference points. The first approach, in the absence of species-specific data, uses basic life history information to determine intrinsic vulnerability to decline and ultimately extinction risk (Dulvy et al. 2004). Population parameters such as body growth rate, age at maturity and natural mortality can be used for this approach but there is likely to be inter-population variation around species averages and should be considered in such an assessment (Hutchings 2001). These measures of the biological and ecological characteristics allow species to be ranked by their relative productivity or susceptibility to exploitation, and can be combined with distributional and behavioural information to qualitatively rank species vulnerabilities (Dulvy et al. 2004).

The second approach, time-series, uses the population growth rate, the actual rate at which the population changes each year, over at least ten years. Data on population growth for even a short period of time are not available for most species, even for some of those that are targeted by commercial fisheries (Castro et al. 1999). A similar approach relies on stock assessment models and an index of relative abundance, coupled with information on catch and effort (Hilborn & Walters 1992). However, this often requires the standardisation of CPUE to remove factors other than abundance that affect trends through time, which is done by separating the comparable data sets from the non-comparable (Maunder & Punt 2004). A particular problem in mixed line-fisheries is the removal of records that include non-targeted effort. The third way to assess populations uses demographic information such as fishing mortality or using life-cycle analysis that requires growth, survival and reproductive output according to age or stage class (Dulvy et al. 2004). Though these rates are rarely available because it is difficult to estimate the age of many chondrichthyans (Cailliet et al. 2005).

False Bay chondrichthyan assessment

Owing to the general paucity of catch data for some species and lack of detailed demographic information for others, a combination of the time-series and life history approaches were chosen to assess chondrichthyan vulnerability to exploitation in False Bay. Testing the significance of species trends using annual catch abundance in each of the main fishing methods allowed for the subsequent merging of trends across data sets to determine an overall population trend. Though p values of less than 0.1 were considered significant, the combination of methods will reduce the likelihood of a type II error. These trends were compared to life history attributes that informed the level of resilience of each species to exploitation. This assessment identified a handful of cartilaginous species that are experiencing population catch declines, likely as the result of exploitation, in addition to species that are increasing or have unknown catch trends.

The majority, twenty chondrichthyan species and one genus, in False Bay showed no significant population trend or no common trend and were therefore assessed as *unknown*. Population trends for these species may have been masked for two reasons. Firstly, poor taxonomic resolution of species identification by commercial operators was predominantly to blame for a lack of detailed catch records. This occurs because chondrichthyans are either not fishers primary catch, and as a result fisherman are not concerned with identifying the catch and/or they cannot identify the individual to the species level. For example the genus, *Raja,* has four species found in False Bay and were regularly caught as bycatch in all major fisheries, but because these species are not marketable they were often lumped together as skates. As a result the population assessment could only be done for the group as a whole. This may result in the decline of rare or less resilient species to go unnoticed. Secondly, bycatch species are often not marketable and are instead discarded and unreported, also obscuring catch trends. Regardless, the lack of reporting inhibits valuable investigation into population status that would otherwise be used to encourage management or regulations reducing their exploitation.

Thirteen chondrichthyans were considered of *conservation concern* in False Bay. Evidence of catch decline in one or more fishing method, compounded by very-low productivity, small population or endemicity, and/or mortality threat linked to habitat warranted automatic listing. Firstly, low or very-low productivity results in a chondrichthyan's inability to withstand heavy exploitation and therefore was important when considering a species extinction risk. For example, *N. cepedianus* has been commercially targeted in False Bay and shows evidence of highly significant decline in angling catches.

Secondly, Musick (1999b; 2000c) and the IUCN (2011) emphasise the susceptibility of small populations, endemics and range-restricted species to exploitation and the importance of protecting these species from exploitation. It is because of this limitation that some species, including some that did not show catch declines, were listed as *conservation concern.* For example, all catshark species (family Scyliorhinidae) were considered vulnerable because most are endemic to only a portion of South Africa's short coastline and inhabit areas of heavy exploitation where they are caught as bycatch in most fisheries. In addition, catshark populations are likely to be smaller than originally believed because of imprecise taxonomic identification and the recognition of distinct subpopulations that have little to no genetic mixing (Human 2003a, b).

Thirdly, most chondrichthyan species move between multiple habitats, but are nonetheless associated with a primary habitat (Field et al. 2009). With these habitats come various threats or maybe protection, from different fishing methods and should be considered when assessing species vulnerability to exploitation. For example, deep-water habitats are more protected than shallow inshore areas of False Bay due to the trawling ban. As a result species that spend the majority of their lives in these areas, such as *Squalus* species, are better protected than those that spend their entire lives in shallow, rocky reefs targeted by anglers (e.g. *Scyliorhinidae* spp.) and therefore these species should receive priority protection. On the other hand, species that move in and out of False Bay are also subject to additional fishing pressure. Demersal trawling and pelagic longlining are common practice outside of False Bay and for the numerous pelagic, semi-pelagic and deep-water species this represents an increased mortality source. Therefore consideration should be made for the species habitat and behaviour in a population assessment. *P. warreni*, a deep-water species, was considered more vulnerable for this reason.

One species and one genus were considered *vulnerable* in False Bay. *C. capensis* was listed as *vulnerable* because it is showing signs of catch decrease, is targeted and caught as bycatch in multiple fisheries and it is endemic with low productivity—culminating in increased susceptibility to over exploitation. *Raja* spp. were also listed as *vulnerable* because of multiple weakly significant declines in catch, low productivity and because they are regularly caught as bycatch in all False Bay fisheries.

Two species were categorised as *threatened* in False Bay because of their continued exploitation and vulnerability to overexploitation. Firstly, *T. megalopterus* showed a highly significant catch decline in recreational angling. In addition, *T. megalopterus* has very-low productivity and is endemic to southern Africa, also increasing risk. The frequency and quantity with which this species is regularly caught in multiple fisheries is cause for concern and requires further monitoring. Secondly, *G. galeus* shows the most dramatic population trends. CPUE decreased drastically across the linefishery, recreational angling, the beach seine and demersal longline fisheries, most of which have historically targeted this species for commercial use. Exacerbating the decline of *G. galeus* is its very-low resilience to exploitation; it can take females up to 15 years to reach maturity and they can live for over 50 years (Walker et al. 2006).

Despite numerous population reductions two species were found to have increasing catch trends and were therefore considered to have *stable* populations in False Bay. Most obvious was, *M. mustelus*, showing significant increase in three fishing methods, commercial linefish, recreational angling and demersal longline despite having very-low productivity. *M. mustelus* is an abundant species and currently seems to be coping with the increased exploitation in many fisheries. However this level of exploitation will eventually result in the typical 'boom-and-bust' pattern of heavily targeted chondrichthyans, as seen for species in other areas around the world (Stevens et al. 2000).

Though less clear, *C. brachyurus*, showed a weakly significant increased CPUE in commercial linefish and demersal longling catch. However *C. brachyurus* has very-low productivity, has a Southern African subpopulation and is continually being exploited in fisheries, and therefore should be monitored for future catch trends. It could be argued that the increase in population of these two species is the result of release from predation by larger shark species that are experiencing population reductions (Myers et al. 2007). Although these two species are currently showing signs of resilience toward exploitation, a precautionary approach should be taken in regards to these species harvest and monitoring and management should is encouraged. It is only when populations are reduced at greater rates than gains achieved through density compensation that large population decline become inevitable (Field et al. 2009).

Though life history attributes are generally considered to correspond with the level of extinction risk in fish, including chondrichthyans (Musick 1999b; Garcia et al. 2008), this was interestingly not the case in False Bay. The level of a species' productivity did not necessarily coincide with the catch trends (increasing or decreasing) found and therefore could not be used alone as a proxy to predict species vulnerability to exploitation.

2.4.6. Conclusion

The catch trend analysis presented here is not considered as proof of impact on chondrichthyans or lack of impact by fisheries, but rather as a way to prioritise investigation of the impacts of fishing on known vulnerable and ecologically important species. Though extinction has not been widespread in marine species thus far, there is no reason for lack of concern; threats such as human overpopulation, habitat damage and exploitation will continue to grow (Musick et al. 2000a).

In order of priority, species already showing reductions in population should receive immediate consideration for conservation management or protection. Secondly, due to their significant contribution to chondrichthyan catches the most commonly caught species (*G. galeus, M. mustelus*, *R. annulatus*, *C. capensis* and *N. cepedianus*), regardless of catch trends, should be the focus of chondrichthyan fisheries management, beginning with improved catch monitoring, as well as a detailed population assessment. Thirdly, species listed as a *conservation concern* should receive scientific investigation to better determine their threat status. Finally, species with *unknown* status, most of which are bycatch species, clearly require investigation, but this may simply be achieved by improving taxonomic resolution of catch reporting and reporting bycatch.

Recreational angling, commercial linefish, and beach seine (providing species are not lumped and instead identified) have been recognised as the least selective methods, covering the greatest area within False Bay and hold the most information on the broadest spectrum of species. Although longline catch diversity was lower than trawl, and considerably lower than the three methods just mentioned, this technique may need to be included in a suite of methods covering chondrichthyans in False Bay to effectively cover all habitats. These methods offer valuable tools to monitor chondrichthyan populations with little extra effort required. However, it is vital that operators reporting landed and discarded catch to firstly identify to the species level and secondly identify species correctly.

CHAPTER 3.

STUDY REVIEW AND SYNTHESIS

3.1. Conclusion

"The loss of a single species is an evolutionary tragedy in its own right; however, when species loss triggers the degradation of entire biological communities, the importance of their conservation increases" (Field et al. 2009).

The direct and indirect overexploitation of chondrichthyans is not a new problem and has been a concern of scientists for decades. In recent years, however, the call for action has become harder to ignore, and as a result the number of global and regional assessments has increased. Because many species, particularly those with restricted ranges, spend a majority of their time in coastal waters protected by a country's Exclusive Economic Zone, conservation management and protection may be most beneficial in the hands of nations and actors on a local scale. It is because of this that population assessments of locally occurring species is necessary.

The False Bay catch trend analysis of individual fishing methods revealed significant trends (increasing or decreasing) in ten species and two genera. The combination of methods, however, revealed just five common trends, these were trends representative of the species population as a whole, usually across more than one method. Two species showed a common trend of increase, whereas two species and one genus showed a decreasing trend in catch from False Bay.

Although population decline is probably the most important factor when assessing risk of cartilaginous species to exploitation, factors like range and habitat also play a key role in the success or failure of a species to survive and should be considered when prioritising species for conservation management. The False Bay chondrichthyan populations were evaluated and placed into one of five threat categories: *stable, vulnerable, threatened, conservation concern* or *unknown*. These categories can be used as a way to prioritise species for research, conservation management or protection in False Bay.

The majority of taxa had *unknown* exploitation threat status, primarily because of the lack of catch records. For these rarely caught species decisions need to be made as to how best manage them without more information. Similarly, the species of *conservation concern* are identified as such largely because they were endemic or part of a Southern African subpopulation and taken as bycatch in False Bay fisheries. These species also require more information, but ironically the best way to get this data, currently, are through exploitive fishing methods. Moreover to continue monitoring the species populations that are currently *stable* and those that are *vulnerable* or *threatened* by exploitation in False Bay these species must continue to be caught because fishing is currently the best monitoring technique.

With the public perception of shark attack as ever-present in False Bay, the implementation of shark nets is on the horizon but this would be a tragedy in its own right. The uniquely high diversity found within the Bay would be negatively impacted, perhaps irreversibly. Shark nets, or gill-nets, indiscriminately entangle not only harmless chondrichthyan species, but also marine mammals and sea birds (Dudley & Simpfendorfer 2006), some of which are protected species. Though the total catches are comparatively small to fishery catches, shark nets are an important mortality source for small endemic populations (Field et al. 2009).

3.2. Study limitations

Despite the general paucity of chondrichthyan catch data worldwide, I was able to compile a fairly extensive catalogue of data from a range of methods spanning decades in False Bay. However, some of the data sets were not exhaustive in that records were either missing from some recreational anglers or commercial operators, and/or annual records were missing entirely for period of time creating gaps in catch trends.

The most substantial limitation, however, was the level of taxonomic resolution. Significant chondrichthyan trends were found, but with more species-specific data it would have been possible to categorise additional chondrichthyans to a vulnerability status. For example, skates were largely lumped together into one category, *Raja* spp., and I was therefore forced to assess them as a group. Herein lies the problem, the genus *Raja* contains species with low and medium productivity, but if the more vulnerable skate is declining in abundance the trend will be masked by the more fecund species, possibly resulting in extinction.

The lack of specific life history and demographic information of some chondrichthyan species additionally complicates their assessment. Without these statistics an assessment can still be accomplished by testing a range of parameter estimates in stock population models, or by using Musick's (1999b) approach of risk assessment using a combination of available parameters, however this may result in an overly conservative assessment.

3.3. Recommendations

Despite progress, both domestically and internationally, in terms of managing fisheries that directly or incidentally catch chondrichthyans, there are still gaps to address before improved conservation of cartilaginous fishes can be achieved. Firstly fisheries management practices, including regulations and agreements, should be conservative erring on the side of the health of the resource rather than short-term economic gain (Musick et al. 2000b), particularly given the circumstance of inadequate knowledge of most cartilaginous species.

Secondly, effective management requires reliable, species-specific information on biology and total mortality (landings and discards) and precautionary limits in the face of uncertainty (Lack & Sant 2006). To acquire more detailed information to understand the magnitude of exploitation as well as its effect on chondrichthyan population the serious deficiencies in both the reporting and handling of the catch statistics must be resolved, and of particular concern is the poor species discrimination complicating stock assessments (Bonfil 1994). To quickly resolve this issue trained fisheries observers should be required on fishing vessels for a majority of the time, simultaneously ensuring compliance to quotas or regulations (Musick et al. 2000b). Additionally, the lack of scientific data on catch statistics and post-release survival rates makes it difficult to quantify the impact of any fishery on South Africa's inshore resources (WWF 2011). Research into the various methods for the most commonly caught species would drastically improve catch estimates for bycatch.

3.4. Future research

Aside from addressing the above mentioned limitations in chondrichthyan assessment and gaps in chondrichthyan knowledge there are still areas in which research needs to be done. Firstly, the negative impacts of fisheries on chondrichthyan species are becoming common knowledge. However, the impacts of pollution, exotic marine organisms and climate change, among others, on cartilaginous species are almost entirely known. Although these threats are sure to have detrimental impacts on already vulnerable species, this will require close, long-term monitoring of chondrichthyan species—something that is not widely done today.

Additionally, researchers need to explore methods to reduce bycatch of chondrichthyans in fisheries. Because bycatch represents such a significant proportion of the total cartilaginous catch, the implementation of any such method would have a substantial positive impact on the abundance of many chondrichthyan species. Also detailed knowledge of the distribution and behaviour of these species will enhance efforts to protect particularly vulnerable species. Though a handful of marine protected areas exist in False Bay attention must be paid to those species that do not occur in these areas, as well as to those that do and whether they spend a majority of their time within the protected zone. This knowledge can be used to inform the future placement of marine protected areas to benefit the maximum number of chondrichthyan species. Finally, with the increasing popularity of ecotourism people are beginning to realise chondrichthyans are considerably more valuable alive than their once off removed value. This paradigm shift represents a significant boon in favour of chondrichthyan conservation, but the long-term impacts for both human and marine communities involved needs to be investigated further.

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Appendix I. The origin of information used to assess chondrichthyan exploitation in False Bay. Included are the individual data sources, fishing methods, the time periods and sample sizes collected.

Source	Method	Period	Sample size
CGH (1898; 1899; 1903; 1904)	Demersal Trawl Commercial catch	1897 – 1903 (excluding 1989-1901)	93 hauls
Gilchrist (1921); von Bonde (1929a,b; 1932a,b; 1933)	Demersal Trawl Scientific survey	1920, 1927 – 1932 (excluding 1928 and 1930)	51 hauls
Cape Peninsula Club records (unpublished)	Recreational Angling	1969 – 1986	-
Ocean's 50 Club records (unpublished data)	''	1971 – 1986	-
Northern's Club records (unpublished data)	''	1978 – 1986 (excluding 1980 & 1981)	479 anglers
InterClub records	Competition Angling	1989, 1992 – 1995	-
InterClub records	''	2006 – 2011	2 087 anglers
S. J. Lamberth (unpublished data)	Beach Seine Commercial catch	1974 – 1987	4 669 hauls
S. J. Lamberth (unpublished data)	''	1983 – 2003	7 284 hauls
Lamberth (1994)	Beach Seine Scientific survey	1990 – 1992	311 hauls
Clark et al. (1996)	''	1991 – 1993	264 hauls
Lamberth et al. (1995)	''	1993	11 hauls
National Marine Linefish System	Linefishing Commercial catch	1985 – 2010	179 197 boat days
C. Da Silva (unpublished data)	Demersal Longline Commercial catch	1992, 1996 – 2003, 2007 – 2011	> 228 951 hooks
Cliff (1983)	SCUBA Diving Sightings	1978 – 1980	13 dives

Lechanteur (1999)	‘’	1993 – 1995	>1 442 dives
Lechanteur & Griffiths (2001)	‘’	1993, 1995 – 1996	24 transects
Lechanteur (1999)	Spearfishing Competition catch	1992 – 1996	875 dives
Prochazka (1998)	Poison Scientific Survey	1994	500 samples

Appendix II. Chondrichthyan (*) and teleost species recorded in each fishing or sampling method occurring in False Bay, South Africa, for which records exist, in the 20th century and the total number identified.

Species	Commercial Beach Seine	Survey Beach Seine	Linefish	SCUBA Census	Recreational Angling	Trawl	Demersal Longline	Rotenone	Spearfishing
*Alopias vulpinus**			5.2		11				
*Callorhinchus capensis**	3146	1716	14.5		35	7			
*Carcharhinus brachyurus**	27	100	612.4		1352				1
*Carcharhinus brevipinna**			38.2						
*Carcharhinus limbatus**					2				
*Carcharias taurus**	1	2			66				
*Carcharodon carcharias**	2	1	10.2		2				
*Dasyatis brevicaudata**		3			2				
*Dasyatis chrysonota**		1076			487	13			
*Dasyatis thetidis**					3				
Elasmobranch spp.*	650		72819.6		985	881	5		
*Etmopterus granulosus**						6			
*Galeorhinus galeus**	65		16692.8		362		7965		
*Gymnura natalensis**	24	18			150				
*Halaelurus natalensis**		1							
*Haploblepharus edwardsii**		21		21	39			23	
*Haploblepharus pictus**		1		1				12	
*Isurus oxyrinchus**	2		303.8				93		
*Mustelus mustelus**		1442	12950.6	1	359	7	3298		30
*Myliobatis aquila**	30	1589	98.8		172	233			
*Narke capensis**		6							
*Notorynchus cepedianus**	1		3228.1	2	301		170		5
*Pliotrema warren**						3			
*Poroderma africanum**		3		4	9	2		4	
*Poroderma pantherinum**			34.5	1	3				

Species	Commercial Beach Seine	Survey Beach Seine	Linefish	SCUBA Census	Recreational Angling	Trawl	Demersal Longline	Rotenone	Spearfishing
*Prionace glauca**			128.4				17		
*Pteromylaeus bovinus**		4			103				
Raja spp.*	27	93			184	1395	1063		
*Rhinobatos annulatus**	9	5388	7.5		876	105			
Scyliorhinidae spp.*	2000		21			1			
*Sphyrna zygaena**	4		27.93		11				
*Squalus acanthias**						1166			
*Squalus megalops**			1298		237	113	1		
*Torpedo fascomaculata**		1							
*Torpedo marmorata**					7	95			
*Triakis megalopterus**		5	793.4	2	1537				9
Achirus capensis						1			
Alectis ciliaris		1							
Aluterus monoceros		2							
Amblyrhynchotes honckenii		7307							
Antennariidae spp.						9			
Argyrosomus hololepidotus		1				1			
Argyrosomus inodorus	31575	3610	858367		1986	92			
Argyrozona argyrozona			229992	47		16030			
Arnoglossus capensis						10			
Atherina breviceps		64575							
Atractoscion aequidens	18		352904		16	2			
Austroglossus microlepis	8	1							
Batrichthys apiatus								2	
Batrichthys felinus								16	
Bidenichthys capensis								71	
Blennioclinus brachycephalus								5	
Blennius spp.				1					

Appendix II. Continued

Species	Commercial Beach Seine	Survey Beach Seine	Linefish	SCUBA Census	Recreational Angling	Trawl	Demersal Longline	Rotenone	Spearfishing
Blennophis anguillaris								8	
Blennophis striatus								4	
Boopsoidea inornata			5490	100	3				
Brama brama			120						
Caffrogobius agulhensis								14	
Caffrogobius caffer		4							
Caffrogobius nudiceps		520							
Caffrogobius saldanha								68	
Cancelloxus longior		9							
Cantherhines pardalis		2							
Carangidae spp.		5			1				
Unidentified *Carangidae*									
Chaetodon marleyi									
Cheilodactylus fasciatus			2	631				90	21
Cheilodactylus pixi				9				1	
Cheimerius nufar		8	1112						
Chelidonichthys capensis	77	360	1092		60	10689			
Chelidonichthys kumu						140			
Chirodactylus brachydactylus			1730	11					106
Chirodactylus grandis			24	10					32
Chorisochismus dentex								17	
Chrysoblephus cristiceps			92		3				
Chrysoblephus gibbiceps	5		38299		3	655			4
Chrysoblephus laticeps			400690	29	48	271			363
Clinidae spp.				33		12			
Clinus agilis		32							

Species	Commercial Beach Seine	Survey Beach Seine	Linefish	SCUBA Census	Recreational Angling	Trawl	Demersal Longline	Rotenone	Spearfishing
Clinus cottoides								23	
Clinus latipennis		26							
Clinus nematopterus								10	
Clinus rotundifrons								19	
Clinus superciliosus		104				1		17	
Clinus taurus								3	
Clinus venustris								9	
Coccotropsis gymnoderma								2	
Coelorinchus fasciatus						124			
Congiopodus spinifer						93			
Congiopodus torvus						48		2	
Coryphaena hippurus		3	2						
Cremnochorites capensis								109	
Cymatoceps nasutus	1		16.2		3				
Cynoglossus capensis		25				3033			
Dactyloptena peterseni		1							
Decapterus macrosoma		3256							
Decapterus russelli			148						
Dichistius capensis	128	55	1745	3	3638				98
Dichistius multifasciatus		1			3				
Diplecogaster megalops				1					
Diplodus cervinus	9	2	8132	25	111	10			14
Diplodus sargus	6052	1831	11518	30	1310	5			20
Draculo celetus		1							
Ecklonaichthys scylliorhiniceps								22	
Elops machnata	15	3							
Engraulis capensis		35072							

Appendix II. Continued.

Species	Commercial Beach Seine	Survey Beach Seine	Linefish	SCUBA Census	Recreational Angling	Trawl	Demersal Longline	Rotenone	Spearfishing
Engraulis japonicus		1							
Epinephelus guaza			59		24				
Epinephelus marginatus									1
Eptatretus hexatrema								1	
Fucomimus mus		1						11	
Gaidropsarus capensis								27	
Galeichthys ater								96	
Galeichthys feliceps	10797	276	1965		1	6			
Genypterus capensis			1998.66		1	19			
Gilchristella aestuaria		367							
Undescribed Gobiesocidae								9	
Gonorhynchus gonorhynchus		1				16			
Gymnocrotaphus curvidens			681		7				110
Halidesmus scapularis								330	
Helicolenus dactylopterus			2289			24			
Heniochus acuminatus		1							
Heteromycteris capensis		136							
Katsuwonus pelamis			3552						
Kuhlia mugil		1							
Lichia amia	294	262	18		56				
Lithognathus lithognathus	63496	4572	510.25		4580	129			1
Lithognathus mormyrus	22243	129	64						
Liza dumerilii		108							
Liza richardsonii	26299350	644518	980		18				
Liza tricuspidens		419							
Lophodiodon calori		1							

Species	Commercial Beach Seine	Survey Beach Seine	Linefish	SCUBA Census	Recreational Angling	Trawl	Demersal Longline	Rotenone	Spearfishing
Merluccius capensis	1		9894			2119			
Monodactylus falciformes		1							
Mugil cephalus	370	70							
Muraenoclinus dorsalis								7	
Oplegnathus conwayi			36						5
Ostracion spp.		2							
Pachymetopon aeneum			5634						9
Pachymetopon blochi	39		1685910	2153	193	222			279
Pachymetopon grande			38		28				
Pagellus bellottii natalensis		13							
Paracallionymus costatus						23			
Parascorpis typus		1	21						20
Parupeneus rubescens		19							
Pavoclinus graminis								4	
Pavoclinus litorafontis								8	
Pavoclinus myae								69	
Pavoclinus pavo								55	
Pavoclinus profundus								4	
Pelagocephalus marki		1							
Petrus rupestris			701.6		4				1
Polyprion americanus			27.8						
Polysteganus undulosus									
Pomadasys commersonnii	724	43			46				
Pomadasys olivaceus			445						
Pomatomus saltatrix	86333	17423	439351		694				
Psammogobius knysnaensis		601							
Pterogymnus laniarius		2	747408			23606			
Rhabdosargus globiceps	21454	15127	1308857		99	19385			

Appendix II. Continued.

Species	Commercial Beach Seine	Survey Beach Seine	Linefish	SCUBA Census	Recreational Angling	Trawl	Demersal Longline	Rotenone	Spearfishing
Rhabdosargus holubi	5	47	16	26	18				
Rhabdosargus sarba					2				
Sarda sarda	80		575.5		104				3
Sardinops sagax	9749	7408							
Sarpa salpa	116537	8680	31030	496	41				
Scomber spp.				250					
Scomber colias						51			
Scomber japonicus	33402	1	797282		1				
Scomberomorus commerson	750		186.25		127				
Scombridae spp.			126560						
Scorpaena scrofa								1	
Seriola lalandi	204142	7641	662773		1432				64
Serranidae spp.			8						
Solea bleekeri		107							
Solea capensis						7			
Solea fulvomarginata		3				1			
Soleidae spp.	4					613			
Sparodon durbanensis	5		4		110				1
Sphyraena acutipinnis		16							
Spicara axillaris			490			21			
Spondyliosoma emarginatum	5553	296	223824	158	3	18			
Stephanolepis auratus		2							
Stromateus fiatola	522	273			12.85	2			
Synaptura marginata		1							
Syngnathus acus		2						1	
Syngnathus temminckii		6							

Species	Commercial Beach Seine	Survey Beach Seine	Linefish	SCUBA Census	Recreational Angling	Trawl	Demersal Longline	Rotenone	Spearfishing
Tachysurus feliceps				2					
Thunnus alalunga			38826.2		453				
Thunnus albacares			1010.38		21				
Thunnus obesus			36.9						
Thyrsites atun	1908		4971020		114	5			
Trachinocephalus myops		3							
Trachinotus africanus		1							
Trachinotus botla		1							
Trachurus trachurus	220030	19158	132836	800		3			1
Trachyscorpia eschmeyeri						2			
Umbrina canariensis		59							1
Umbrina robinsoni	6388	1396	8		1057				
Uranoscopus archionema						1			
Xiphias gladius			12.32						
Zeus capensis						42			
Zeus faber		12	4			15			
Mixed fish			25845			18280			
Unidentified fish	1760		54173		11.37	340			

Appendix III. Mean individual species weight, in kilograms, used to convert National Marine Linefish System (NMLS) data from mass to number of individuals for fish and chondrichthyan (*) species caught in the commercial linefishery in False Bay.

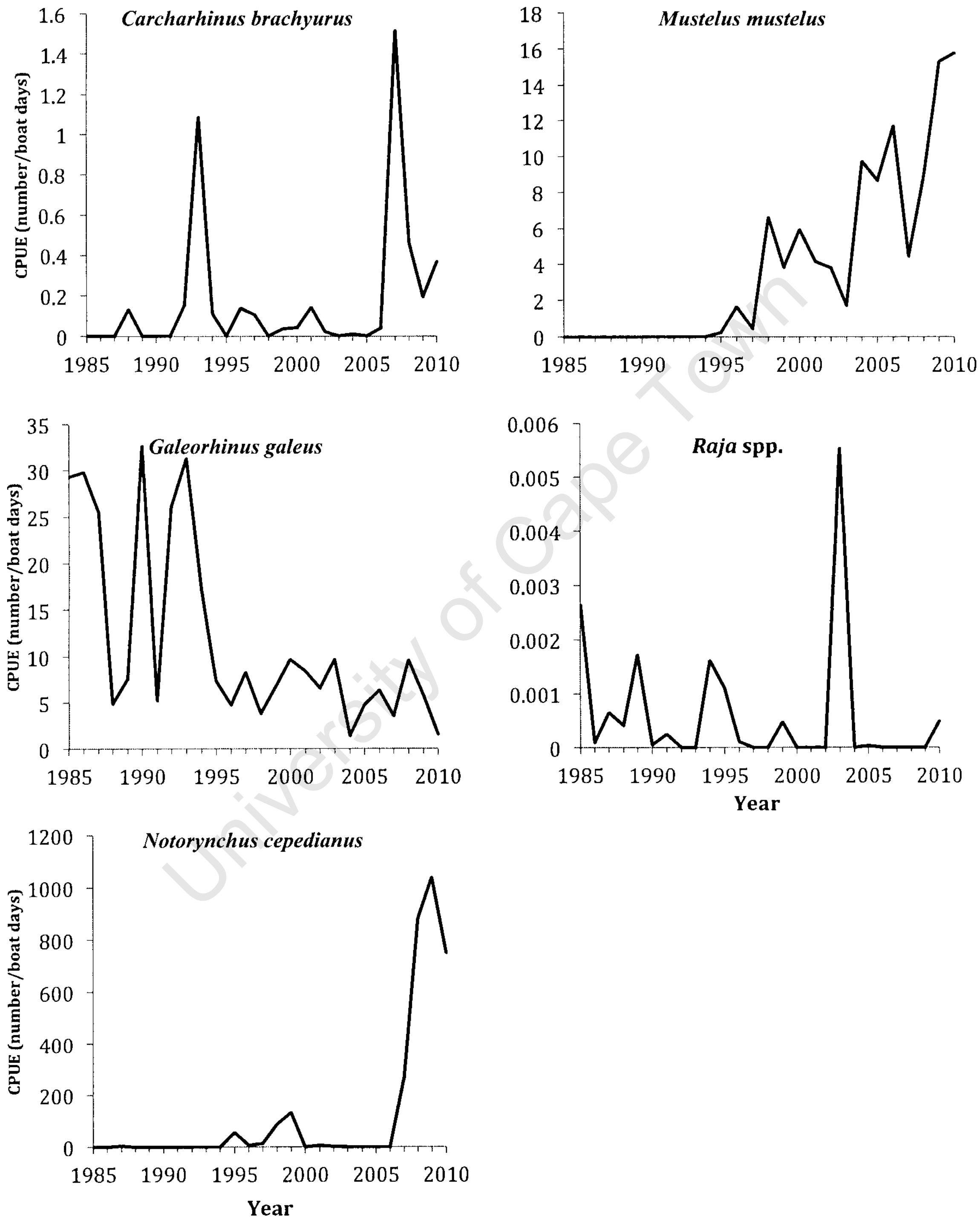
Scientific name	**Common name**	**Mean weight (kg)**
*Alopias vulpinus**	Thresher sharks	10
Argyrosomus inodorrus	Kob	2
Argyrozona argyrozona	Carpenter	1
Atractoscion aequidens	Geelbek	4
Boopsoidea inornata	Fransmadam	0.2
Brama brama	Atlantic pomfret	1
*Callorhinchus capensis**	St. Joseph	2
*Carcharhinus brachyurus**	Copper shark	10
*Carcharhinus brevipinna**	Spinner shark	5
*Carcharodon carcharias**	Great white shark	500
Cheilodactylus fasciatus	Redfingers	0.5
Cheimerius nufar	Santer	1
Chelidonichthys capensis	Cape gurnard	1
Chirodactylus brachydactylus	Twotone fingerfin	0.2
Chirodactylus grandis	Bank steenbras	2
Chrysoblephus cristiceps	Dageraad	1
Chrysoblephus gibbiceps	Red stumpnose	1
Chrysoblephus laticeps	Roman	1
Coryphaena hippurus	Dolphinfish	2
Cymatoceps nasutus	Poenskop	5
Dichistius capensis	Galjoen	1
Diplodus cervinus	Zebra	1
Diplodus sargus	Blacktail	1
Elasmobranch spp.*	Sharks	5
Epinephelus guaza	Yellowbelly rockcod	1
Galeichthys feliceps	Seacatfish	1
*Galeorhinus galeus**	Soupfin shark	5

Genypterus capensis	Kingklip	3
Gymnocrotaphus curvidens	Janbruin	1
Heilcolenus dactylopterus	Jacopevers	1
*Isurus oxyrinchus**	Shortfin mako	10
Katsuwonus pelamis	Skipjack tuna	2
Lichia amia	Garrick	5
Lithognathus lithognathus	White steenbras	8
Lithognathus mormyrus	Sand steenbras	0.5
Liza richardsonii	Southern mullet	0.2
Merluccius capensis	Hakes	2
*Mustelus mustelus**	Smooth-hound shark	5
Myliobatiforme spp.*	Rays	20
*Notorynchus cepidanus**	Cow shark	10
Oplegnathus conwayi	Parrotfish	1
Pachymetopon aeneum	Blue hottentot	1
Pachymetopon blochii	Hottentot	1
Pachymetopon grande	Bronze bream	1
Parascorpis typus	Jutjaw	1
Petrus rupestris	Red steenbras	5
Polyprion americanus	Wreckfish	5
Pomadasys olivaceum	Piggy	0.2
Pomatomus saltatrixx	Elf	1
*Poroderma pantherinum**	Leopard catshark	2
*Prionace glauca**	Blue shark	5
Pterogymnus laniarius	Panga	0.5
Rhabdosargus globiceps	Stumpnose	1
Rhabdosargus holubi	Cape stumpnose	0.5
*Rhinobatos annulatus**	Lesser guitarfish	2
Sarda sarda	Striped bonito	2
Sarpa salpa	Strepie	0.2
Scomber japonicus	Mackerel	1
Scomberomorus commerson	King mackerel	4
Scombridae spp.	Mackerels and tunas	1

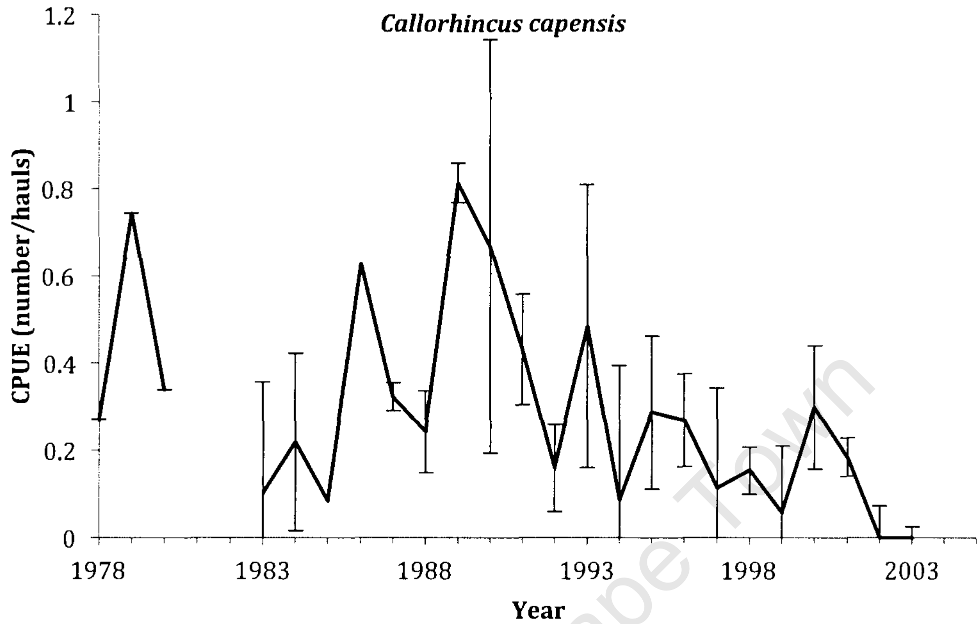
Appendix III. Continued.

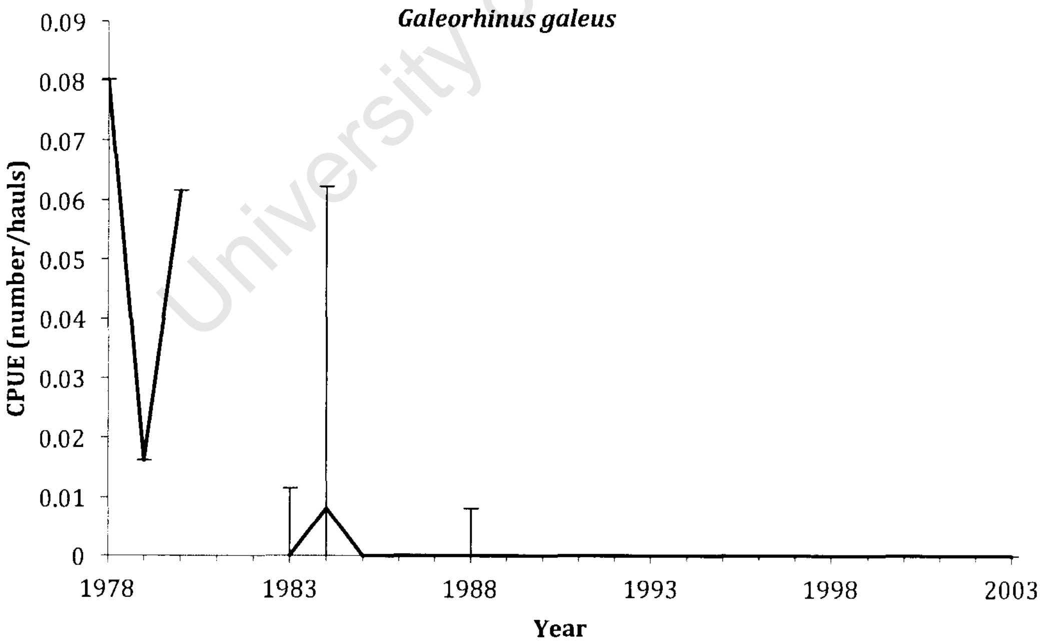
Scyliorhinidae spp.*	Shysharks	1
Seriola lalandi	Yellowtail	3
Serranidae spp.	Rockcods and seabass	1
Sparodon durbanensis	White musselcracker	5
*Sphyrna zygaena**	Hammerhead sharks	15
Spicara axillaris	Windtoy	0.2
Spondyliosoma emarginatum	Steentjie	0.5
*Squalus megalops**	Spiny dogfishe	1
Thunnus alalunga	Albacore	15
Thunnus albacares	Yellowfin tuna	50
Thunnus obesus	Big-eye tuna	50
Thyrsites atun	Snoek	3
Trachurus trachurus	Cape horse mackerel	0.5
*Triakis megalopterus**	Spotted gully shark	10
Umbrina robinsoni	Baardmans	1
Xiphias gladius	Swordfish	50
Zeus faber	John dory	1
–	Mixed redfish	1
–	Fish	1

Appendix IV. Mean annual catch per unit effort (CPUE) of five shark species caught in False Bay's linefishery showing a significant catch trend between 1985 and 2010.

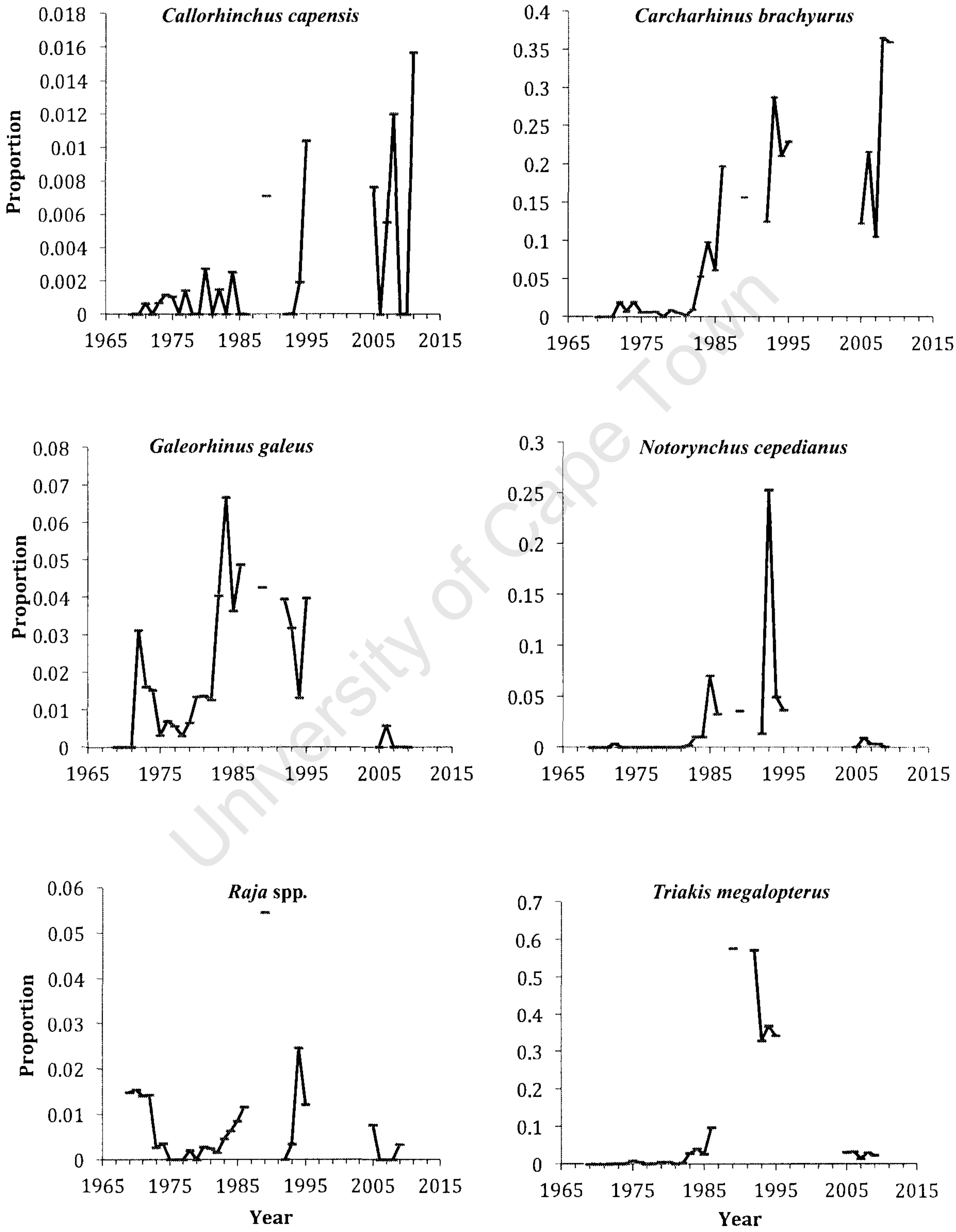


Appendix V. Mean annual catch per unit effort (CPUE) for two chondrichthyan species caught in commercial beach seine nets in False Bay between 1974 and 2003.

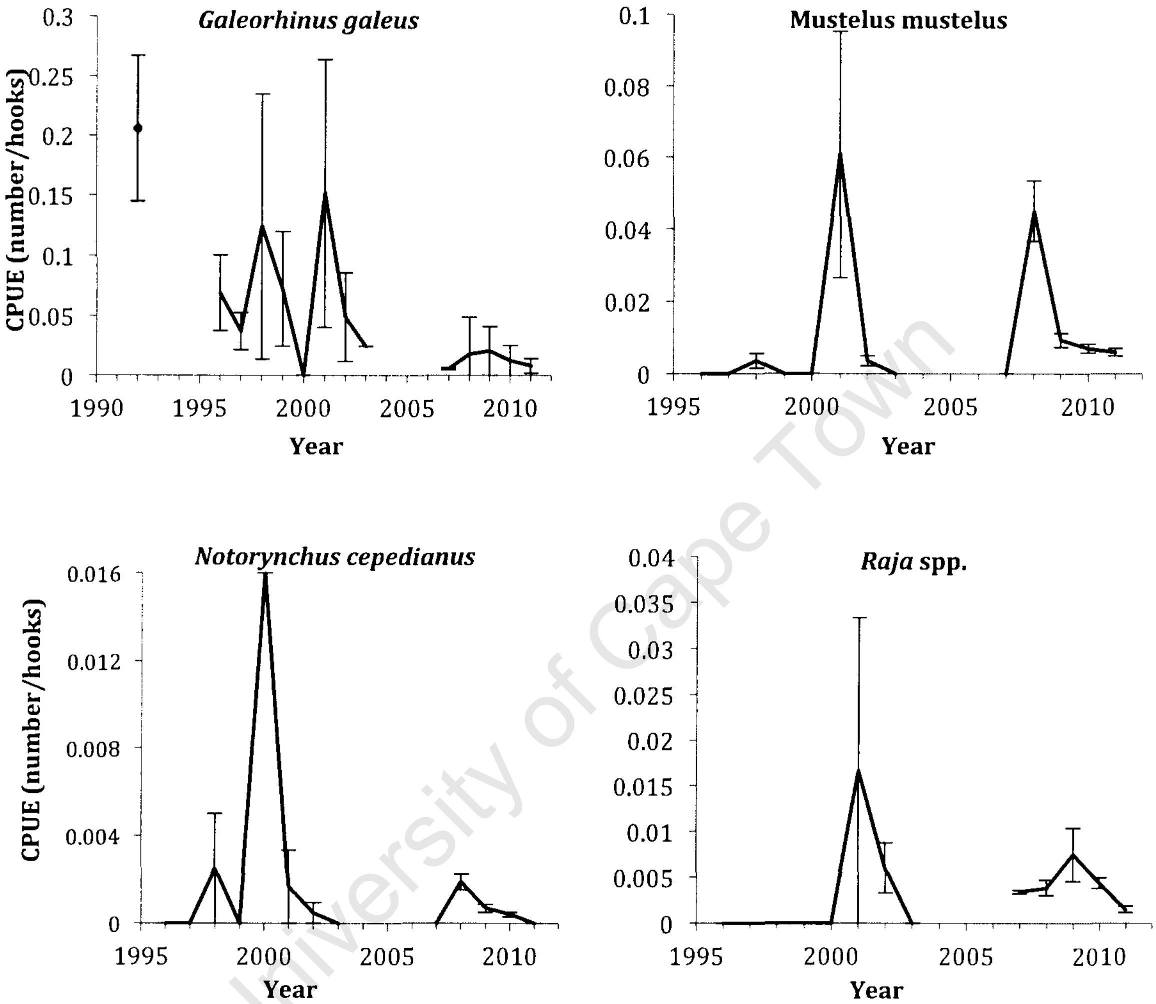




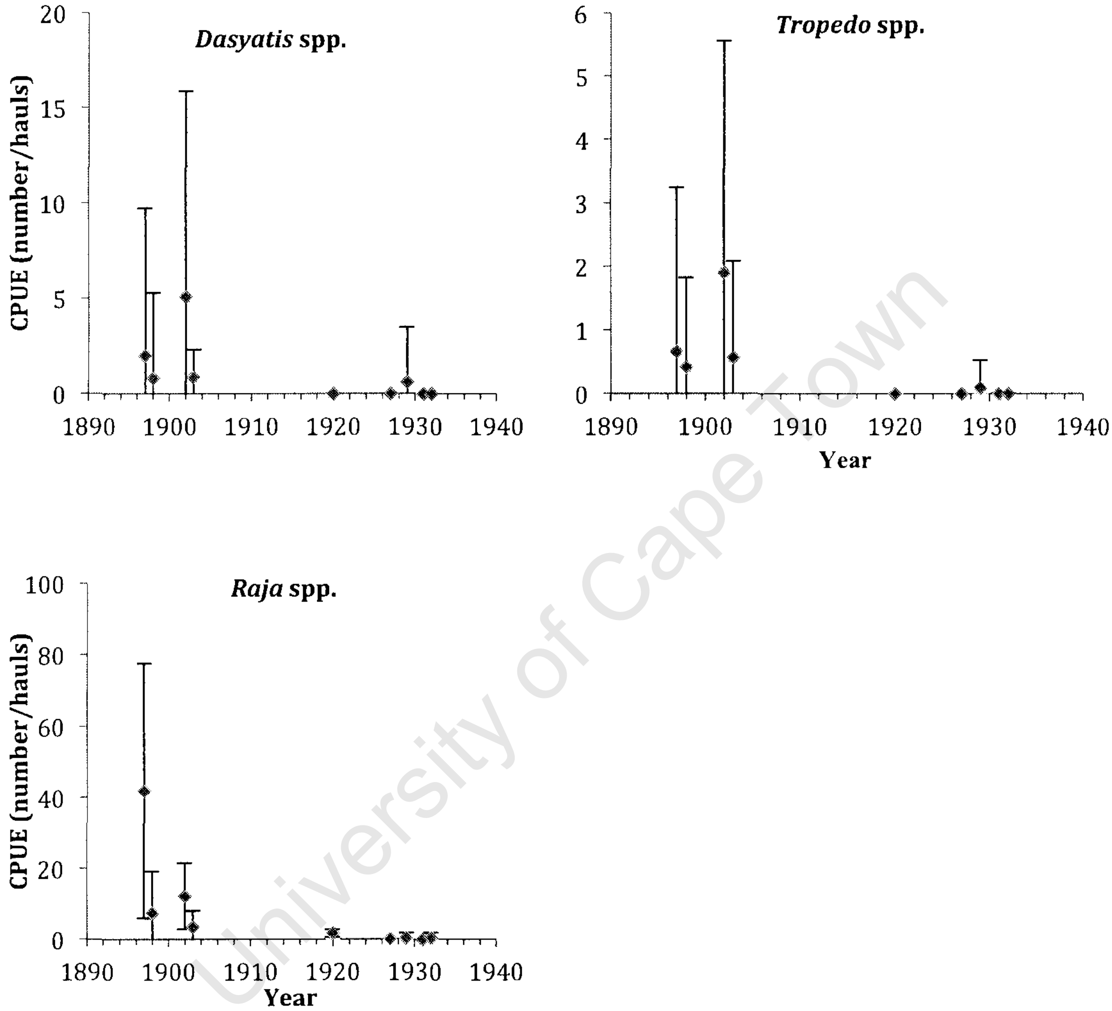
Appendix VI. Trends in catch proportion of six chondrichthyan species regularly caught by recreational anglers in False Bay between 1969 and 2011.



Appendix VII. Mean catch per unit effort (CPUE) for four chondrichthyan species caught in commercial shark demersal longlines in False Bay between 1992 and 2011.



Appendix VIII. Mean catch per unit effort (CPUE) for three genera showing declining catch trends in historical trawl surveys in False Bay between 1897 and 1932.



Appendix IX. False Bay chondrichthyan vulnerability assessment. CL (commercial linefish), CBS (commercial beach seine), RA (recreational angling), DL (demersal longline)

Species	CL	CBS	RA	DL	**Common trend**	**Productivity**	Small range/ endemic	Primary habitat	**Status in False Bay**
Alopias vulpinus						Very Low		Pelagic	UK
Callorhinchus capensis		-			None	Low	x	Demersal	**V**
Carcharhinus brachyurus	+			+	Increasing	Very Low	x	Surf zone/reef	**ST**
Carcharhinus brevipinna						Very Low		Pelagic	UK
Carcharhinus limbatus						Very Low		Reef/pelagic	UK
Carcharias taurus						Very Low		Surf zone/reef	UK
Carcharodon carcharias						Very Low		Pelagic	UK
Dasyatis spp.			+		None	Very Low		Demersal	UK
Dasyatis brevicaudata						Very Low		Reef	UK
Dasyatis chrysonota			+		None	Very Low	x	Soft sediment	**CC**
Dasyatis thetidis						Very Low		Soft sediment	UK
Etmopterus granulosus						Low		Demersal	UK
Galeorhinus galeus	- -	-	- -	- -	Decreasing	Very Low		Demersal	**TH**
Gymnura natalensis						Very Low	x	Demersal	**CC**
Halaelurus natalensis						Very Low	x	Reef	**CC**
Haploblepharus edwardsii						Very Low	x	Reef	**CC**
Haploblepharus pictus						Very Low	x	Reef	**CC**
Isurus oxyrinchus						Low		Pelagic	UK
Mustelus mustelus	+ + +		+	+	Increasing	Very Low		Demersal	**ST**

Species	CL	CBS	RA	DL	Common trend	Productivity	Small range/ endemic	Primary habitat	Status in False Bay
Myliobatis aquila						Very Low		Soft sediment	UK
Narke capensis						Low	x	Soft sediment	**CC**
Notorynchus cepedianus	+		- -		None	Very Low		Reef	**CC**
Pliotrema warreni						Very Low	x	Demersal	**CC**
Poroderma africanum						Very Low	x	Reef	**CC**
Poroderma pantherinum						Very Low	x	Reef	**CC**
Prionace glauca				+	None	Low		Pelagic	UK
Pteromylaeus bovinus						Very Low		Demersal	UK
Raja spp.	-		-		Decreasing	Low		Demersal	**V**
Rostroraja alba			-		None	Low		Soft sediment	UK
Raja clavata						Low		Demersal	UK
Raja miraletus						Medium	x	Soft sediment	UK
Raja straeleni						--		Soft sediment	UK
Rhinobatos annulatus			+		None	Very Low	x	Soft sediment	**CC**
Scyliorhinus capensis						Very Low	x	Reef	**CC**
Sphyrna zygaena						Very Low		Pelagic	UK
Squalus acanthias						Very Low	x	Demersal	**CC**
Squalus megalops						Very Low		Demersal	UK
Torpedo fuscomaculata						--		Demersal	UK
Torpedo marmorata						Very Low		Demersal	UK
Triakis megalopterus			- -		Decreasing	Very Low	x	Reef	**TH**